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FREEVU – A Computerized Freeway Traffic Analysis Tool

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FREEVU – A Computerized Freeway Traffic Analysis Tool

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Abstract: FREEVU, Freeway Evaluation with Visual Understanding, is a personal computer simulation model for freeway design. It allows the user to specify a freeway section including lanes, grades, exits and entrances, posted speed limits, detector locations, etc. The section can then be viewed to confirm the proposed design.

A variety of traffic situations can then be specified including percent trucks, distribution of car and driver characteristics, entrance and exit percentages, etc. The user can simulate the traffic situation for various freeway design alternatives and then evaluate the design through two methods. Firstly the information from the specified detector locations can be used to evaluate volumes, average speeds and densities over time. Secondly an animation of the simulation results can be viewed to evaluate weaving sections, stability of traffic flow, impacts of trucks, and so forth.

FREEVU is user friendly with extensive menus and default values. The simulation has been validated for a number of different sites and generally found to be an accurate simulation of traffic flow. Recommendations are made for further simulation and design enhancements.

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Table of Contents

Acknowledgements x

1/ Introduction 1

1.1/ Urban Freeway Congestion 1

1.2/ The Transportation Planning Process 2

1.3/ Simulation - An Evaluation Tool 4

1.4/ Current Models Available 6

1.5/ Structure of Report 8

2/ Freeway Traffic Flow Theory 10

2.1/ Basic Uninterrupted Flow Theory 10

2.2/ The Traffic Stream 13

2.3/ The Vehicle 14

2.4/ The Driver 16

2.4.1/ Human Limitations 16

2.4.2/ Human Self-Interest 18

2.5/ Geometry 19

3/ The Planning and Design Environment 21

4/ FREEVU - The Model 27

4.1/ Freeway Specification Module 30

4.1.1/ Section Geometry 33

4.1.2/ Detectors 36

4.1.3/ Vertical Grades 36

4.1.4/ Speed Limits 37

4.1.5/ Data Input Summary 37

4.1.6/ Displaying a Section 39

4.2/ Simulation Module 39

4.3/ Translation Module 42

4.4/ Traffic Performance 43

4.4.1/ Animation 43

4.4.2/ Numerical Output 44

4.5/ Program Limitations 45

4.6/ Summary 46

5/ Key Algorithms and Assumptions 47

5.1/ Car Following Theory 47

Table of Contents (continued)

5.1.1/ Effect of Driver Characteristic *k* 49
5.2/ Vehicle Generation 50
5.3/ Effect of Posted Speed Limit 52
5.4/ Lane Changing Algorithms....54
5.4.1/ Geometry 55
5.4.2/ Behavioural Manoeuvres 57
5.5/ Maximum Attainable Acceleration 63
5.6/ Detector Loops 64
6/ Model Validation and Evaluation....66
6.1/ Introduction 66
6.2/ Burlington Skyway Validation 69
6.2.1/ Validation 71
6.3/ Mississauga Validation 75
6.3.1/ QEW - Mississauga Data Set....76
6.3.2/ Video Tape Data 77
6.3.3/ FHWA Data Set 79
6.3.4/ Validation 81
6.4/ Summary.... 86
7/ Conclusions and Recommendations 88
7.1/ Summary.... 88
7.2/ Conclusions.... 90
7.3/ Recommendations 92
Bibliography 94

Appendices:

A/ Validation Details.... 100
A.1/ FHWA Data and Simulation Results 100
A.2/ Vehicle Data File 126
B/ Technical Program Data 130
B.1/ Simulation Program Subroutine Documentation 130
B.2/ General Variable Listing....135
B.2.1/ Single Variables 135
B.2.2/ One Dimensional Arrays....137
B.2.3/ Two Dimensional Arrays....138

Table of Contents (continued)

B.2.4/ Three Dimensional Arrays 139

B.3/ Simulation Module Program Listing 141

C/ User's Manual 179

C.1/ Hardware Requirements 179

C.2/ Tutorial 179

C.2.1/ General Data Input 180

C.2.2/ Initialize and Execute Simulation 187

C.3/ Output Files 192

C.4/ Dealing With Problems 194

List of Tables

2.1/ Measures of effectiveness 13
4.1/ Permissible physical features and lane types 35
4.2/ User options when displaying section 39
4.3/ User options when zooming 40
4.4/ User options when watching animation 44
4.5/ Restrictions applicable to FREEVU 46
5.1/ Comparison of desired and produced volumes 52
5.2/ *Comfortable* acceleration and speed transition deceleration rates 54
5.3/ Table of notation 64
6.1/ Comparison of loop detector and video volumes for eastbound QEW 79
6.2/ FHWA sections used for validation 80
6.3/ Observed non-mandatory lane change rates per vehicle kilometre 80
6.4/ Comparison of simulated and observed non-mandatory lane change rates per vehicle kilometre 81
6.5/ Comparison of simulated and observed total three lane volumes for eastbound QEW 82
6.6/ Qualitative summary of detailed validation results 85
A.1/ Aggregated observed data for I-295 southbound 102
A.2/ Simulation results for site 2: I-95 southbound 104
A.3/ Aggregated observed data for I-95 southbound 105
A.3/ Aggregated observed data for I-95 southbound - continued 108
A.3/ Aggregated observed data for I-95 southbound - continued 109
A.4/ Simulation results for site 3: I-395 southbound 111
A.5/ Aggregated observed data for I-395 northbound 112
A.6/ Simulation results for site 4: I-405 northbound 114
A.7/ Aggregated observed data for I-405 northbound 114
A.8/ Simulation results for site 5: I-405 southbound 117
A.9/ Aggregated observed data for I-405 southbound 118
A.9/ Aggregated observed data for I-405 southbound - continued 119
A.9/ Aggregated observed data for I-405 southbound - continued 121
A.9/ Aggregated observed data for I-405 southbound - continued 122
A.10/Manoeuvres rates per vehicle kilometre observed on QEW 123
A.11/Simulation and observed data: QEW manoeuvre section 124

List of Tables (continued)

A.12/Current vehicle classes 127
A.13/Vehicle data file - car data 128
A.14/Vehicle data file - truck data 129
C.1/ Restrictions applicable to FREEVU 181
C.2/ Manoeuvre types recorded 193
C.3/ Possible errors when saving Data 197

List of Figures

1.1/ Potential strategies for reducing congestion 2
1.2/ A simplified system analysis process 3
1.3/ HCM chapters required for analysis of a typical freeway 5
2.1/ Idealized relationships between speed, flow, and density for uninterrupted flow 11
2.2/ Speed-flow relationship for eastbound QEW in mississauga 12
2.3/ Interaction between tractive effort and resistance 15
2.4/ The human reaction process 17
2.5/ Functional relationship between roadway classes 19
3.1/ Comprehensive planning process 22
3.2/ A typical urban transportation planning process 22
3.3/ Comparison of level of detail for different analysis applications 24
3.4/ Designer - model environment 26
4.1/ FREEVU - modular structure 28
4.2/ FREEVU - menu structure 29
4.3/ Data requirements and input order 32
4.4/ Freeway segment and portion to be modelled 32
4.5/ Schematically represented dection to be modelled 33
4.6/ Section geometry data input form 34
4.7/ Example of a lane type change due to a geometric change outside of the current lane 35
4.8/ Grade specification input screen 36
4.9/ Speed limit input screen 37
4.10/ Three segment types used to define a freeway section 38
4.11/ Freeway section representation internal to the simulator 40
5.1/ Car following theory 48
5.2/ Effect of driver characteristic *k* on acceleration 50
5.3/ Acceptable deceleration as a function of remaining distance 56
5.4/ Desired lane change illustration 56
5.5/ Driver decision process for passing manoeuvre based on "self-interest" 58
5.6/ Frustration index 59
5.7/ Time headway between two vehicles 60
5.8/ Probability function for passing on left 61
5.9/ Probability function for passing on right 62

List of Figures (continued)

5.10/ Probability function for yielding to the right.....63
6.1/ Various levels at which validation can be focussed.....66
6.2/ Chronological development and testing of FREEVU.....68
6.3/ Location of monitored freeway section in Burlington.....70
6.4/ Plan and profile of Burlington skyway simulated section.....70
6.5/ Extended section of QEW simulated.....72
6.6/ Morning peak - average volume comparison.....73
6.7/ Morning peak - average speed comparison.....74
6.8/ Location of Mississauga QEW section.....76
6.9/ Simulated portion of QEW in Mississauga.....77
6.10/ Non-mandatory lane change rates versus average lane volume.....78
6.11/ Comparison of simulated and observed average lane volumes for QEW section in Mississauga.....83
6.12/ Comparison of simulated and observed average lane speeds for QEW section in Mississauga.....84
6.13/ Variation in simulation results with constant inputs.....86
A.1/ I-295 southbound between 11th Street and Howard Road.....101
A.2/ I-95 southbound at Backlick Road.....103
A.3/ Proportion of merging vehicles as a function of distance along acceleration lane.....106
A.4/ Observed driver behaviour due to anticipation of ramp merge.....107
A.5/ I-395 southbound at Duke Street.....110
A.6/ I-405 northbound at Mulholland Drive.....113
A.7/ I-405 southbound at Santa Monica Blvd......116
A.8/ QEW site on which manoeuvre rates simulated.....124
A.9/ Effect of driver type on distribution of driver sensitivity.....12
B.1/ Flowchart of simulation module program structure.....131
B.2/ Lane change mechanics.....132
C.1/ Plan view of freeway section to be modelled.....182
C.2/ Profile of freeway section to be modelled.....182
C.3/ Geometry of lane 1.....183
C.4/ Geometry data input for lane 1.....184
C.5/ Geometry data input for lanes 2, 3, 4 and 5.....185
C.6/ Detector data input.....186

List of Figures (continued)

C.7/ Vertical curvature data input 186
C.8/ Speed limit data input 187
C.9/ Origin-destination matrix alteration screen 190
C.10/Interpretation of origin-destination matrix 191
C.11/Available output options....192
C.12/Portion of example output file AVERAGES....193
C.13/Portion of example output file MANOEUVR 194
C.14/Portion of example output file LNCHGS....195
C.15/Portion of example output file TIME....196

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Chapter 1

Introduction

1.1 Urban freeway congestion

> 'Eastbound core and collectors are heavy this morning due to volume of traffic. Stop and go on the Parkway right down to the Viaduct, again just volume of traffic. Looking west of the city, the QEW is heavy...'

A typical morning traffic report heard on any one of a dozen Toronto area radio stations. Change the names and the same report could be heard in any major urban centre across North America. Congestion — the bane of every highly concentrated urban centre — is a major problem facing society in the 90's, but congestion is not a new phenomenon. Two thousand years ago, Julius Caesar dealt with "urban" congestion by restricting vehicle access to the business areas of some of the large cities in the Roman Empire during peak periods. Today, congestion is an even greater problem, and nowhere is congestion more evident than on the urban freeway networks.

Efficient freeway corridors are essential for urban growth — for the transportation of goods and services, as well as much of the employment base. In addition, the state of the freeways has important impacts on the environment — congestion leads to increased fuel consumption, a non-renewable resource; increased pollution having far reaching impacts on humans, animals and plants, as well as global weather patterns; and increased costs to commercial carriers and commuters due to delay.

There is no denying the existence of congestion; however, the question facing transportation engineers, planners, and political leaders is, 'What, if anything, can or should be done about it?'

A small minority believes that urban congestion may, in part at least, alleviate itself due to future changes in work force demographics, corporate restructuring, and economic trends [1].

The vast majority believes that congestion exists, will only continue to become worse and must be dealt with.

A number of strategies exist by which the reduction of congestion can be addressed, all of which can be placed into two main categories: demand reduction and capacity expansion. Figure 1.1 illustrates a number of strategies and indicates into which category each falls. Though not a comprehensive list, this illustrates the variety of potential approaches available.

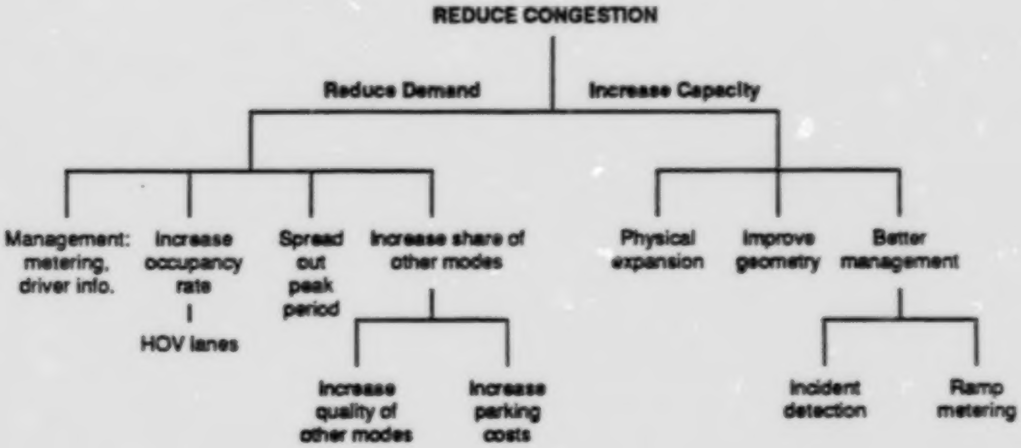

REDUCE CONGESTION
Reduce Demand
Increase Capacity
Management: metering, driver info.
Increase occupancy rate
HOV lanes
Spread out peak period
Increase share of other modes
Increase quality of other modes
Increase parking costs
Physical expansion
Improve geometry
Better management
Incident detection
Ramp metering

Figure 1.1: Potential strategies for reducing congestion

1.2 The transportation planning process

All of these strategies require some decision process, incur costs, and produce varied results. In order to effectively choose the appropriate strategy for a given situation, some evaluation structure is required. Many similar evaluation processes have been developed [2] [3]. A simplified process, as presented by Khisty, is illustrated in Figure 1.2.

Much of the process deals with the recognition and identification of the problem and the goals and objectives. Within the context of urban freeways, the problem

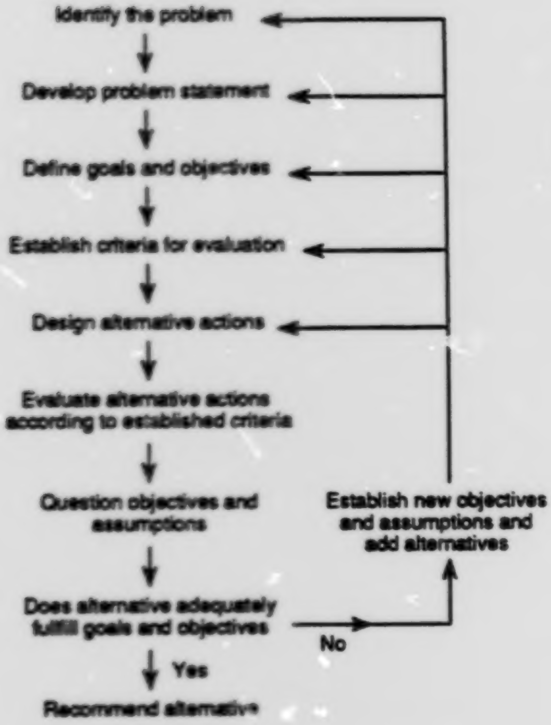

Identify the problem
Develop problem statement
Define goals and objectives
Establish criteria for evaluation
Design alternative actions
Evaluate alternative actions according to established criteria
Question objectives and assumptions
Establish new objectives and assumptions and add alternatives
Does alternative adequately fulfill goals and objectives
No
Yes
Recommend alternative

Figure 1.2: A simplified system analysis process (Source: [3])

is one of congestion and the goal is to implement one or more strategies with the objective of achieving some specific state; i.e. a goal may be to implement a HOV (high occupancy vehicle) lane with the objective of reducing peak hour demand by 10%.

Criteria for evaluation must be defined prior to the search for potential solution approaches. These must be measures that evaluate in a quantitative manner whether or not the approach successfully fulfills the goals. Again, in this context, a measure for evaluation may be the volume to capacity ratio (v/c), average travel speed, average delay, travel time, or some other measure.

Having generated a number of alternative actions, there is the need to evaluate these in terms of effectiveness. This requires a knowledge of the expected results. In terms of freeway operations, the most commonly used evaluation tool in North America is the 1985 Highway Capacity Manual (HCM) [4].

The HCM presents procedures based for the most part, on aggregated empirical data obtained from various sites. Unfortunately, freeways are complex systems and the determination of capacity, or expected traffic flow characteristics is rather difficult to quantify. Difficulties arise due to each freeway section being somewhat unique such that general, or average solutions often do not produce adequate results. In addition, freeway traffic with its dynamic behaviour is difficult to quantify in aggregate form. This limits the use of the HCM for complex or unique situations.

The HCM deals with individual homogeneous components of the freeway section in different chapters. Thus if the freeway section contains all of these components, at least 4 chapters must be referenced (Figure 1.3). Each component of the section must be analyzed and then some synthesis of these individual evaluations must be performed to evaluate the section as a whole.

In addition, though the HCM analysis can provide useful aggregate predictions of expected traffic performance, it does little to enhance the designer's understanding of the dynamic nature of the traffic stream as it traverses the section. This understanding is particularly useful in identifying restrictive geometry, bottlenecks, and other inadequate facility characteristics.

1.3 Simulation — an evaluation tool

Instead of relying on aggregated empirical data, another approach is to model, or *represent* the system in some way. Models can range from an exact physical replica or prototype to some mathematical abstraction [5]. Computer simulation is just one

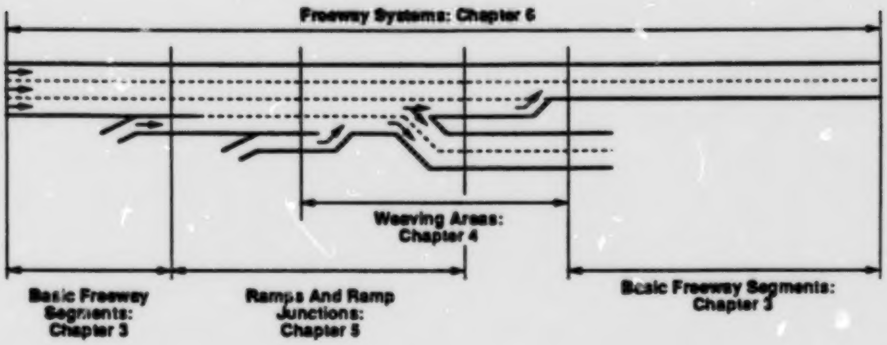

Freeway Systems: Chapter 6
Weaving Areas: Chapter 4
Basic Freeway Segments: Chapter 3
Ramps And Ramp Junctions: Chapter 5
Basic Freeway Segments: Chapter 3

Figure 1.3: HCM chapters required for analysis of a typical freeway

form of *symbolic*, or abstract modelling. The system, in this case the freeway segment of interest, is represented by a computer model constructed of program statements which define physical laws and driver behaviour.

Shannon [6] suggests that simulation be considered when one or more of the following conditions exist:

1. A complete mathematical formulation of the problem does not exist.
2. Analytical methods exist but are too complex, arduous, or inaccurate.
3. Difficulty exists in conducting experiments and observing phenomena in their environment.

In the case of freeway traffic, all three of these conditions exist. A complete mathematical formulation which comprehensively explains all of the dynamics and workings of the freeway system, does not exist. Analytical methods exist, such as the HCM, but are difficult to use for complex situations, and can not provide insights into the dynamics of the system. Lastly, though it is possible to measure existing situations in the field, in most cases, it is not possible to conduct experiments and observe effects. It is simply too costly to add a truck lane, or close a ramp, in order to carry out an experiment.

An additional benefit of simulation is its ability to provide the user with learning experience. The development of a simulation model allows the user to experiment with the system, assisting in the understanding of the problem, the dynamics of the system, and the ramifications of any solutions.

In general, in order to be effective, a simulation model should be [7]:

1. Simple to understand by the user.
2. Directed to a goal.
3. Realistic, such as to avoid absurd results.
4. Easy for the user to control and apply.
5. Complete and accurate on important items.
6. Adaptive, to allow for subsequent enhancements and alterations.

1.4 Current models available

Having ascertained the usefulness of simulation and defined criteria by which to evaluate a simulation model, it was required to determine if such a model existed. If a suitable model was not found, and one suitable for modification was also unavailable, then one would have to be created.

Various detailed reviews of existing simulation models have been conducted and are available in the literature [8] [9] [10]. From these reviews it was determined that there currently exists five basic families of freeway corridor analysis models:

- CORQ
- FREQ
- INTRAS
- MACK
- SCOT

Of these five families, INTRAS[1] is the only microscopic model available for freeway corridors [11]. Since it was desired to investigate microscopic events such as lane changing behaviour and merging at on and off ramps, the INTRAS family was considered.

---

[1] (INtegrated TRAffic Simulation)

The INTRAS [12] model is a stochastic, microscopic model created primarily for studying freeway incidents [10]. The model, originally developed in 1975, was designed to represent traffic, and traffic control elements, in a freeway and surrounding surface street environment. The program, written in ANSI FORTRAN, is large and complex and only suited for main frame use.

INTRAS has been widely applied, with reported uses ranging from freeway reconstruction design evaluation [13, 14, 15], conflict analysis for weaving areas [16], energy conservation studies [17, 18] and as a bench mark for validation of other models [19, 20].

However, according to Van Aerde et al., users of INTRAS have reported problems with some aspects of traffic behaviour [21], such as vehicles merging from on ramps and vehicle behaviour at off ramps.

FOMIS was developed in response to some of these criticisms, and as an attempt to provide the unique capabilities of INTRAS in a more compact and streamlined form [21]. FOMIS restricts the simulation process to the freeway only, eliminates the link structure of INTRAS and reduces vehicle processing to a single scan. This revised structure can be implemented on personal computing systems with reasonable execution times.

To determine if FOMIS would be an effective design tool, it was evaluated according to the previously defined criteria and found to be lacking in the following three areas;

- Simple to understand by the user.
- Easy for the user to control and apply.
- Complete and accurate on important items.

The model was realistic in that it avoided absurd results, it was directed to a goal, and it was adaptive — if one was familiar with FORTRAN, but the model did not have any type of user interface and as such was not simple to understand. Data files needed to be constructed by the user and no error checking of the data format or values occurred. The model, having no interface, was difficult for the user to use. An intimate knowledge of the model's structure and assumptions was necessary to ensure proper usage. The model did not simulate grades, trucks, driver lane change decision making, speed limits, or truck restricted lanes — items felt to be important.

Based on this evaluation, it was felt that FOMIS could be used to form the core of an effective evaluation tool. The model was obtained and extensively modified in order to improve the model's three identified deficient aspects. Attention was focussed on improving the ease with which the model could be applied by a *non-computer expert*, and in ensuring that important items of freeway traffic behaviour were reflected by the model.

1.5 Structure of report

This report is the culmination of work begun in May, 1988. At that time, FOMIS was obtained from Dr. A.G.R. Bullen, of the University of Pittsburgh. The objective was to use this simulation program to study the effect of large trucks on freeway traffic flow.

As work proceeded in understanding and attempting to use the model, a number of possible improvements were envisioned. Full-time research began in May, 1989, at which time the envisioned improvements were incorporated and validated to produce an accurate, user-friendly design and evaluation tool — FREEVU[2].

A very large amount of material is incorporated in this work, making it difficult to document all aspects of FREEVU; its structure, the basis for this structure, assumptions, restrictions, evaluation and directions for application. As a result, this report aims at answering four basic questions about FREEVU — What?, Why?, Where?, and How? What is FREEVU? Why is it needed? Where, within the current design and evaluation process, can FREEVU be used? And how does FREEVU work and how can it be used?

In answering these questions, and keeping in mind that a large amount of material existed, only those program details which were important were discussed at length. Other algorithms and program details have been documented elsewhere and these works are cited where appropriate.

The majority of the work effort expended has been in the development, structuring, programming and debugging of FREEVU. The overall research goal was to create a simple to use freeway traffic analysis tool which would serve to illustrate the potential of such a design tool. Thus, FREEVU itself was the primary objective and as such consumed the greater effort. This report documents the theory and logic behind FREEVU, and evaluates FREEVU 's usefulness as an analysis tool.

Following is a brief description of the purpose and contents of each chapter.

Chapter 2 examines the system being simulated, the freeway, particularly traffic flow theory and the components of the system, and what aspects of each are necessary to simulate, to realistically reflect reality.

---

[2] Freeway Evaluation with Visual Understanding (pronounced *freeview*).

Chapter 3 investigates the design and analysis process. The entire process is examined briefly to provide context. The process for evaluating multilane freeways is examined in detail. It is necessary to understand this process in order that the simulation tool being developed fulfills a useful role within the planning procedure.

Chapter 4 discusses the model structure and presents the structure and strategy underlying the development of the design shell, which contains the simulation model.

Chapter 5 presents a more detailed analysis of the freeway components being modelled. Assumptions and algorithms incorporated in FREEVU are provided.

Chapter 6 provides the validation and evaluation done for FREEVU. A number of data sources are analyzed. Strengths and weaknesses in the model are identified and conclusions are made about the observed data. Conclusions are made about the quality of the model.

Chapter 7 provides conclusions on the abilities of FREEVU and recommendations for potential future modifications.

Appendix A contains the observed data and simulation results used for validation purposes. An analysis of the data also appears, with the results summarized in Chapter 6.

Appendix B contains a description of the program code structure, individual program procedures, and a listing of the simulation module program code.

Appendix C contains a User's Manual for FREEVU which explains details of application, data entry, and dealing with errors.

Chapter 2

Freeway traffic flow theory

The development of any simulation model necessitates the full understanding of the system being represented. In order to simulate the operation of a freeway, an understanding of traffic flow theory and the components of the freeway system is essential.

This chapter outlines basic uninterrupted flow theory, characteristics of the traffic stream, driver behaviour, vehicle dynamics, and geometry. Each aspect will be examined for its effects on traffic flow and importance for simulation. Theory pertaining to car following and driver behaviour algorithms is discussed in Chapter 5.

2.1 Basic uninterrupted flow theory

Uninterrupted flow theory relates three basic measures; volume (or flow), speed and density. Volume is the product of the space mean speed and the density.

$$V = \overline{u}_s \cdot D \tag{2.1}$$

where V is the rate of flow in vph; $\overline{u}_s$ is the space mean speed in km/h; and D is the density in v/km.

In addition to the above relationship, there exist relationships between each pair of measures. Huber reports that a variety of mathematical descriptions of these relationships have been hypothesized including linear [22], logarithmic [23], generalized single-regime [25, 26, 45, 28] and multi-regime models [29]. The simplest, and most commonly used is still the Greenshield model proposed in 1934 (Figure 2.1).

In theory these relationships are clear and explicit, however, in reality the relationships are not so well defined. Considerable variation occurs about the theoretical

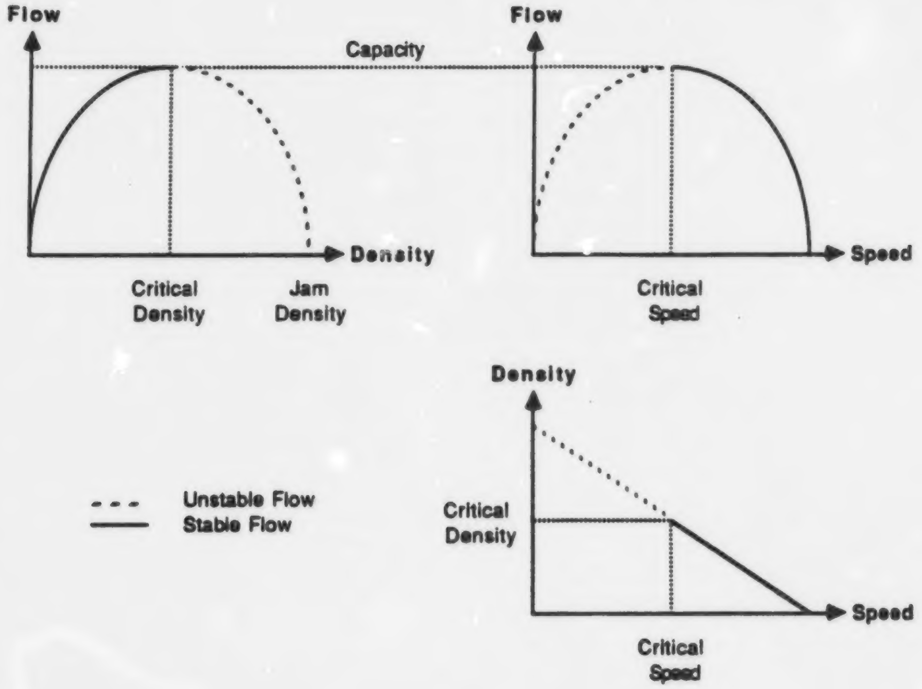

Flow
Capacity
Flow
Density
Critical Density
Jam Density
Speed
Critical Speed
Density
Unstable Flow
Stable Flow
Critical Density
Speed
Critical Speed

Figure 2.1: Idealized relationships between speed, flow, and density for uninterrupted flow

stable flow portion of the curves depicted in Figure 2.1. Approaching the unstable regions, this variation increases substantially, so much so that it is not possible to fit a unique relationship. This is illustrated in Figure 2.2 which shows the observed speed-flow relationship for the eastbound QEW in Mississauga. Five curves, labeled A through E, are depicted, all of which could reasonably be argued to fit the data [30]. Recognizing the presence of this variation is essential when structuring the simulation model in order to ensure that this variation is reflected by the model.

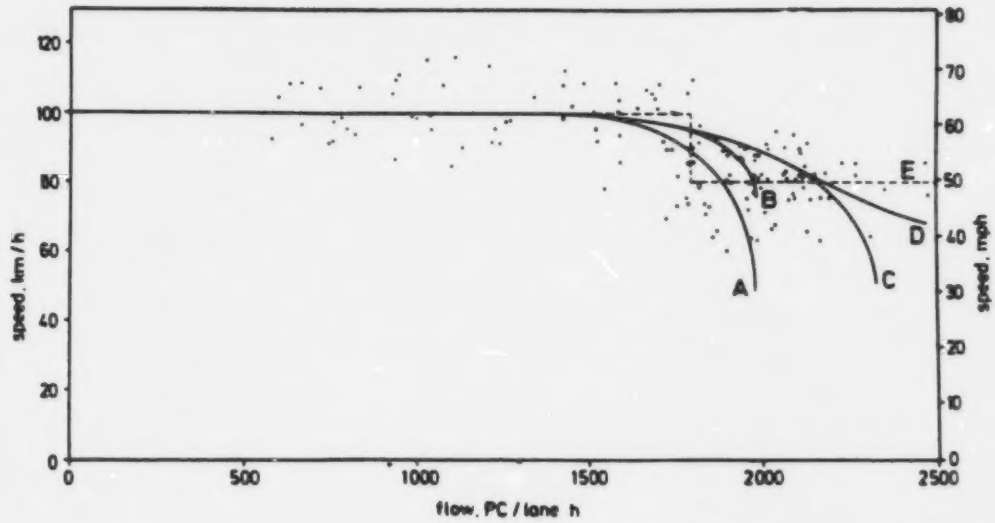


Figure 2.2: Speed-flow relationship for eastbound QEW in Mississauga — 2 minute observations (Source: [30])

As illustrated by Figure 2.2, due to the presence of large variations in observed traffic flow, many models can be devised to fit the data. However, none of these models will be very accurate. A measure of performance derived from one of these models must then also not be very accurate. This dilemma has led to an ongoing debate as to what measures of effectiveness most clearly and accurately reflect the flow conditions on the freeway.

The 1965 HCM [32] selected travel speed as the major factor to use in identifying the quality of flow, or level of service (LOS). During the period between the release of the 1965 HCM and the 1985 HCM, the debate over appropriate measures of LOS continued and the basis for measuring LOS changed. Currently the 1985 HCM lists four different measures of LOS depending on the freeway segment being considered (Table 2.1).

Table 2.1: Measures of Effectiveness (Source: [4], Table 1-2)

Freeway Segment	Measure	Units
Basic Segments	Density	(pc/mi/lane)
Weaving Segments	Mean Travel Speed	(mph)
Ramps	Flow Rates	(pcph)
Multilane Highways	Density	(pc/mi/lane)

Other measures, such as travel time through the section, could be used but are difficult to measure in the field.

It is concluded, that many measures of performance exist but that no one measure clearly and accurately quantifies the level of service of the traffic flow.

2.2 The traffic stream

The dynamic interaction and behaviour of a traffic stream constitutes traffic flow. The traffic stream is comprised of vehicles; predominately varying proportions of different truck and car types. Vehicle types can vary across space and time, with different locations experiencing different proportions of vehicle types within the traffic stream, as well as the vehicle population varying over peak and non-peak hours. In addition, specific characteristics of individual vehicle types, such as truck loadings may also vary over space and time.

The car population within the traffic stream tends not to vary as much as the truck population. Neither is the effect of an individual car as great as that of a truck. For this reason, much work has been done to attempt to understand and quantify the effect of trucks on the behaviour of a traffic stream. The 1985 HCM's method of dealing with truck effects, is to convert each truck into its equivalent in passenger cars. Passenger car equivalents (PCE's) are provided for three truck types; typical, light, and heavy trucks. The PCE's are further stratified by percent grade, length of grade, percent trucks in the traffic stream, and whether the freeway section has four lanes or more. PCE's for a *typical* truck can vary from 2 to 17 for 2% trucks on a four lane freeway depending on the length and steepness of the grade. No PCE's are given for downgrades though it is recommended that field measurements be taken for severe downgrades. The 1985 HCM approach is based on a variety of sources [31, 33, 34].

One difficulty with this method is the use of a *typical* truck. It is not clear that an average truck affects traffic flow in the same manner as does the distribution of different trucks. Also, it is not clear how the effect of the random occurrence of truck platoons or situations of trucks passing one another affects traffic flow. These questions are not easily answered by the aggregated approach taken by the HCM.

It is clear that the effect of trucks on traffic flow is rather significant, particularly for heavy trucks and severe grades and as such must be incorporated into any detailed model of the freeway system.

2.3 The vehicle

The vehicle comprises the basic unit within a traffic stream. It, directed by the driver, interacting with other vehicles, defines the traffic flow characteristics.

Many different vehicle types exist. In terms of operating characteristics, these can be separated into 4 basic classes:

1. Automobiles
2. Trucks
3. Buses
4. Recreational vehicles

For urban freeways, buses tend to comprise a small portion of the traffic stream and can be considered to be a type of truck. The recreational vehicles' class encompasses a wide variety of motorhomes, trailers and campers. This class also usually comprises only a small portion on the urban freeway traffic stream.

The majority of the traffic stream is comprised of cars and trucks. Within the car class, six categories can be identified:

1. small
2. sporty
3. compact
4. medium
5. large

6. vans

And within the truck class, three categories exist:

1. straight
2. tractor-trailer
3. tractor-double trailer

Each category of vehicle has characteristics that set it apart from the other categories. The characteristics of interest are those that affect the performance capabilities of the vehicle. These capabilities are primarily determined by the vehicle's power and mass. Other important factors which influence the vehicle's effect on the traffic stream include length and maximum deceleration rate.

A vehicle's movements are often constrained by laws of motion and the vehicle's characteristics. Acceleration and speed are constrained by tractive effort (TE), tractive resistance (TR) equilibrium. TE is a function of the vehicle's current speed and available engine power. TR is a function of the air drag, rolling friction, grade of roadway and mass of the vehicle. Figure 2.3 illustrates the interaction between TE and TR.

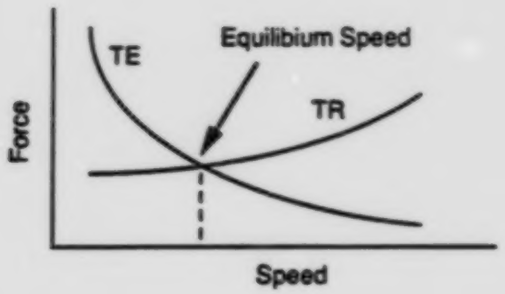


Figure 2.3: Interaction between tractive effort and resistance

A vehicle cannot operate at equilibrium at any speed where TR > TE. A vehicle could operate in a non-equilibrium state with TR > TE if conditions affecting TR were to suddenly change (i.e., change in grade) and the vehicle has not yet attained its new equilibrium state.

Acceleration is limited by the available TE in excess of TR. It is also limited, particularly for trucks, by the speed at which the driver can physically change gears.

Lateral acceleration is a function of the horizontal curve radius and the speed. The maximum lateral acceleration is limited by the superelevation, the side friction coefficient, and for large trucks, the rollover threshold. For most freeway situations, lateral acceleration constraints need not be considered as large curve radii and superelevation permit high speeds without danger of rollover or excessive lateral accelerations. Thus, lateral acceleration need not be explicitly modelled.

2.4 The driver

Human operators are primarily responsible for the variance observed in traffic flow. The impulse to ignore this variance by dealing with the "average" driver can lead to erroneous results as non-average drivers have considerable impact on traffic flow characteristics. Even within similar age groups, abilities to see, process information, make decisions, and react, vary significantly. And these abilities are altered by such factors as fatigue, monotony, age, drugs, and possibly even the type of music listened to [35].

Further changes in abilities can be observed between daylight, dusk and night time, and between ideal, poor, and foul weather.

There exists two categories of human characteristics which affect traffic flow:

- human limitations
- human self-interest

2.4.1 Human limitations

At the very microscopic level of freeway operations is the human operator. Macroscopic measures, so often employed in freeway analysis, are aggregated measures of the decisions and actions of many individual drivers. Variations in these microscopic decisions and actions lead to considerable variation in macroscopic indicators. In order for a simulation model to adequately produce these macroscopic measures, the underlying microscopic events must be properly modelled.

Freeway traffic flow, at its most basic level, is simply the result of numerous drivers all constantly engaged in a process of reacting to external stimuli. Figure 2.4 illustrates the four stages of this process.

The four events illustrated in Figure 2.4 can be described as follows [35]:

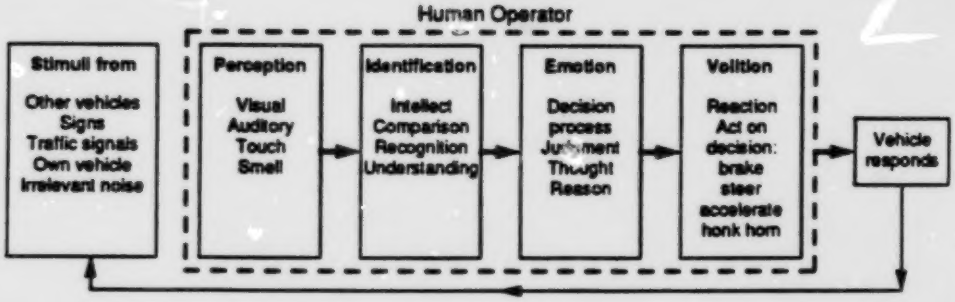

Human Operator
Stimuli from
Other vehicles
Signs
Traffic signals
Own vehicle
Irrelevant noise
Perception
Visual
Auditory
Touch
Smell
Identification
Intellect
Comparison
Recognition
Understanding
Emotion
Decision
process
Judgment
Thought
Reason
Volition
Reaction
Act on
decision:
brake
steer
accelerate
honk horn
Vehicle
responds

Figure 2.4: The human reaction process (Adapted from: [37])

Perception	- seeing the stimuli along with all other perceived objects
Identification	- identification and understanding of the stimuli
Emotion	- the decision making process in which the proper course of action is determined
Volition	- execution of the decided upon action

The sum of the *perception*, *identification*, *emotion*, and *volition* times is referred to as PIEV time and is the total reaction time.

Perception and *Identification* times are primarily dependent on a driver's vision acuity. Visual acuity consists of factors such as dynamic visual acuity (ability to perceive moving objects), depth perception, night vision, and glare recovery. A driver with better visual acuity is more likely to perceive and identify stimuli than a driver with poor vision.

Emotion time is dependent on a driver's ability to make a decision in response to the perceived stimuli. The speed at which a driver is able to make the decision may depend on age, driving experience, and fatigue.

Volition time is primarily dependent on a driver's physical response time. This is the time required for the motor nerves to cause the driver to physically move his/her foot from the accelerator to the brake pedal.

Total PIEV times vary significantly depending on the complexity of the stimuli and on the driver. Under actual conditions, PIEV times have been observed to range from 0.5 to 4.0 seconds [35].

Usually, the 85th percentile is used for design criteria [36]. This design value represents the maximum PIEV time required by 85% of the population. The remaining 15% of the population will then require PIEV time greater than the design value.

At the extreme microscopic end of the scale, simulation can implement a distribution of PIEV times, representing the entire population. A more macroscopic approach would be to define some average PIEV time which is applicable to all drivers. At some intermediate level, two PIEV times may be applied, one for situations in which the driver reacts by accelerating, and another for decelerating. This mesoscopic approach represents a compromise between complete representation and practicality.

2.4.2 Human self-interest

Another characteristic of drivers that controls traffic flow behaviour is their self-interest. Oglesby and Hicks state,

> 'Self-interest, particularly fear of possible accidents, controls many driver decisions.' [37]

Based on self-interest, drivers tend to set their speeds at the highest level at which they feel comfortable in terms of their PIEV time. This is the driver's "desired" speed, and is different for each driver.

This driver self-interest can be termed as driver aggression, or sensitivity. A driver having the impression that he/she possesses a good ability to perceive and react, will tend to be aggressive. These same drivers will be less sensitive to small headways in that they will accept them. Conversely, drivers having the impression that they possess a poor perception reaction time, will tend to be less aggressive and or more sensitive to small headways.

The distribution of driver's sensitivity can vary with time of day, tending to become less sensitive during peak periods and more sensitive during non-peak periods.

Drivers' self-interest also governs their decision making process. This is particularly true for lane changing manoeuvres. Most lane changes are made to satisfy a driver's self-interest. This interest may be some particular destination, requiring that the driver exit the freeway at a specific junction, or it may be to increase speed. Those lane change decisions driven by destination considerations are quite easy to simulate, however those made for non-destination reasons require a model of drivers' decision process. A detailed simulation model must represent this process accurately by employing behavioural algorithms which describe how drivers evaluate their options.

Specific driver characteristics which must be modelled are; some measure of PIEV times, a measure of drivers' aggressiveness, a "desired" speed for each driver type, and the drivers' lane changing decision making process.

2.5 Geometry

Roadway geometry is the basic structure which permits traffic flow. Geometric properties of a section dictate the environment within which traffic flow occurs, and much of the roadway geometry depends on the classification of the road facility. Three primary classifications of roadway facilities exist [38]:

1. **Arteries** serve primarily through movements with little or no land access.
2. **Collectors** serve both through movements and land access.
3. **Local streets** are primarily intended to serve as land access facilities.

As illustrated in Figure 2.5, the three roadway classes define different levels of compromise between mobility and land access.

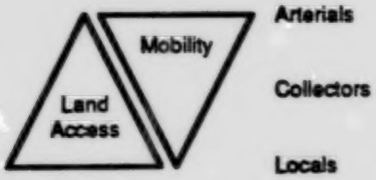


Figure 2.5: Functional relationship between roadway classes

Roadway classification dictates design geometry. Local streets are intended to provide land access and as such have many access points and likely require signalized intersections. Arterials however, function primarily for providing mobility suggesting the existence of few, if any, traffic control features that would detract from this mobility.

For freeways, mobility is of primary concern. The geometry must be compatible with this concern with all design elements intended to promote efficient, safe, high speed flow.

The 1985 HCM states that [39]:

> 'Roadway factors (affecting flow) include all of the geometric parameters describing the roadway, including:
>
> 1. The type of facility and its development environment.

2. Lane widths.
3. Shoulder widths and/or lateral clearances.
4. Design speed.
5. Horizontal and vertical alignment.'

For most of these parameters the 1985 HCM has developed flow capacity adjustment factors from empirical data.

In deciding which parameters to incorporate into the simulation model, consideration was given to what level of detail was required, desired, and practical. These considerations consistently resulted in tradeoffs between desired level of detail and one which was practical. It was decided that FREEVU should have the capabilities to model the following specific geometric elements:

- Unidirectional, multilane freeway segments of 2 to 8 lanes in width.
- Lane adds and drops.
- On ramps — single lane from either the right or left side of the freeway.
- Off ramps — single and multiple lanes from either the left or right side of the freeway.
- Weaving areas.
- Posted speed limit.
- Vertical alignment with the ability to uniquely specify grades for individual lanes.

Other parameters, such as horizontal alignment, lane widths, lateral clearance, road surface conditions, weather, and visibility were not explicitly modelled as these could be dealt with in an aggregated fashion through the use of a posted speed limit (see Section 5.3 for more details). As well, representing all parameters would increase input data requirements and unduly complicate the model without significantly increasing its usefulness or accuracy.

Chapter 3

The planning and design environment

The concepts and structure of the planning and design process have been briefly introduced in Chapter 1. In this chapter, the design process will be examined more closely. Particular attention is to be paid to the role of FREEVU in design, as well as the role of design in the transport planning process and how the process as a whole functions. Investigation begins at the general planning process level and progresses to examine in detail the role of FREEVU within the context of the transportation planning process structure.

As illustrated in Figure 3.1, transportation planning is just one part of a larger planning process. This larger process must consider the inter-relationships between each facet of society and the ripple effects of decisions.

Freeway planning, evaluation and design is the implementation phase of transportation planning [41, 42]. The transportation planning framework is illustrated in Figure 3.2 [43].

The planning process begins with effective organization. Within Ontario, the Ministry of Transportation (MTO) is responsible for all provincial roadways. In many instances, other organizations, such as regional, city, or municipal transportation agencies are also involved. And as indicated by the comprehensive planning process, often organizations representing other facets of society are also affected and involved.

The agencies define planning work programs consisting of two plan elements; long-range elements and transportation systems management (TSM) elements. The long-range element is concerned with identifying major changes to the transportation infrastructure required to meet future demands. The TSM element is concerned with

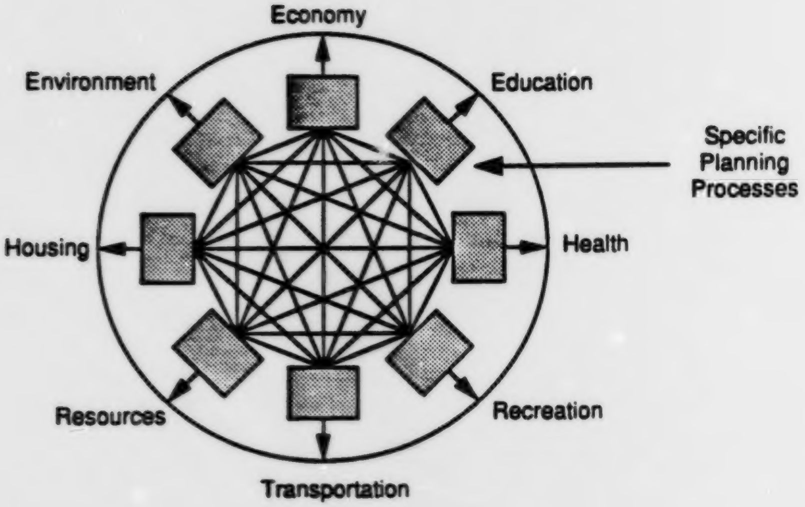

Economy
Environment
Education
Specific Planning Processes
Housing
Health
Resources
Recreation
Transportation

Figure 3.1: Comprehensive planning process (Adapted from: [37] pp.38)

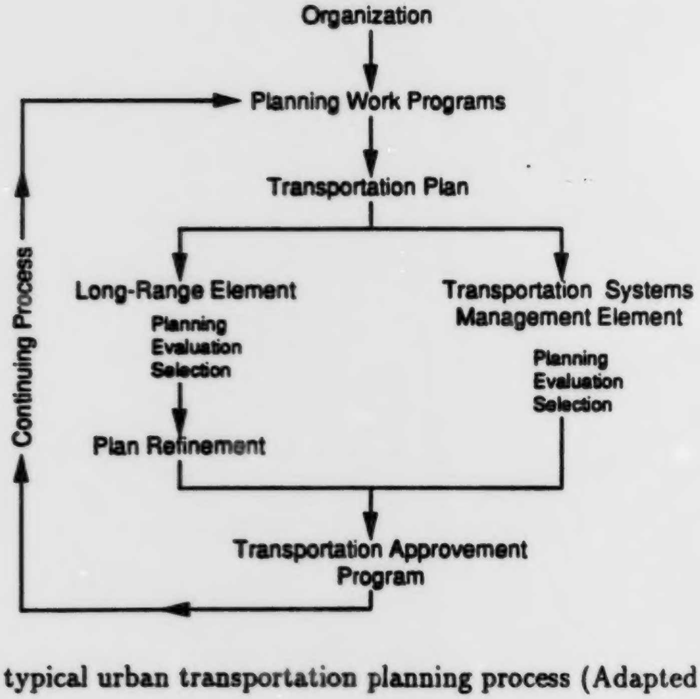

Organization
Planning Work Programs
Transportation Plan
Long-Range Element
Planning
Evaluation
Selection
Transportation Systems Management Element
Planning
Evaluation
Selection
Plan Refinement
Transportation Approvement Program
Continuing Process

Figure 3.2: A typical urban transportation planning process (Adapted from: [43])

making existing transportation facilities as efficient as possible.

For both plan elements, planning tools are used to project transportation needs in the future. Traditionally, there are four phases involved in the forecasting of future travel demand; trip generation, trip distribution, mode usage, and trip assignment.

Alternative plans are developed in response to predicted or observed problems resulting from high demand. These alternatives must be evaluated before one can be selected.

Having selected an alternative action, the plan is refined using more detailed studies.

A structured improvement program is created to ensure that the selected alternative actions are implemented in a coordinated, efficient manner.

Within this planning process, the greatest potential for the application of simulation modelling techniques is that of evaluating and analyzing transportation plans. Depending on the type of transportation plan, long range or TSM, different levels of analysis are required. The 1985 HCM identifies three applications of freeway analysis:

Operational analysis involves a known present or projected future freeway. Given a known or projected geometry, and known or projected traffic conditions, this analysis provides an estimate of the level of service and the speed and density of the traffic stream.

Design consists of the computation of the number of lanes required for the freeway section, based on the projected traffic volume and known design standards. The traffic forecast must be of sufficient detail to identify peaking characteristics, traffic composition, and expected volumes.

Planning has the same objective as design, however, planning focuses on an early and approximate determination before the details of a complete traffic forecast are known. Data sufficient for planning consists of average annual data traffic (AADT), the approximate percent trucks, the general terrain classification, and the desired level of service.

For each application, the primary objective is to determine the number of lanes required to accommodate the expected traffic stream at a selected LOS, as well as the placement and design of access and egress junctions. However, as illustrated in Figure 3.3, the level of detail of the analysis is different for each case.

When evaluating different alternative actions, some measures of the performance of the system is necessary. This is usually accomplished through use of the qualitative

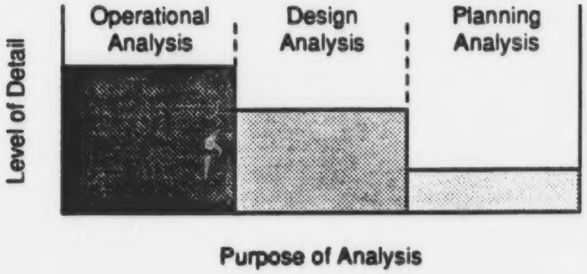


Figure 3.3: Comparison of level of detail for different analysis applications

level of service index. LOS indicates the quality of flow as a letter — ranging from A for excellent flow, to F for unsatisfactory. LOS is based on a number of quantitative measures, the most common presented are [44]:

Volumes or flow rates
    Demand volume
    Discharge volume
Speeds or delay
    Average travel speed
    Spot speeds
    Space mean speed
    Delay per vehicle
Trip times
    Average travel time
Demand-to-capacity ratio
    v/c ratio
Aggregate system measures
    Total travel time
    Vehicle-kilometres travelled
    Vehicle-hours of delay
Others
    Vehicle occupancy
    Number of stops
    Queue lengths

The simulation model is well suited to applications within the framework of evaluating the performance of a freeway section. Not only can the model be used to predict impacts of an alternative plan, but it will also allow the user to gain a greater understanding of how those impacts occur and what are the driving forces behind those impacts. This enhanced understanding will enable the designer to accept or modify the alternative plan.

Simulation is especially useful for evaluating the impacts of freeway elements such as merges, diverges, lane adds and drops, and speed limit changes, all of which have a high impact on traffic flow and this impact is difficult to represent in "average" terms.

To benefit from the model, the designer must interact with the model within the planning process. The model should only require as inputs that information which the designer can produce at this stage in the planning process, and it should produce results which are compatible with the designer's requirements. The designer/model interaction environment is illustrated in Figure 3.4.

The design environment is a detailed element within the planning, evaluation, and selection stage of the transportation planning process. The designer determines an alternative plan, develops suitable traffic characteristics and typical traffic volumes, and then uses FREEVU to evaluate this scenario. The alternative freeway section is input, traffic conditions specified and the simulation executed. Selected outputs are reviewed to evaluate the alternative plan.

In this way, the simulation model can be effectively incorporated into the transportation planning process to enhance the evaluation of alternative actions and better provide an estimation of expected freeway performance.

One major advantage of using FREEVU for evaluating alternative plans is that any measure of performance can be estimated. Only some measures are currently provided by FREEVU, such as average travel time, speed, volume, density, and number of lane changes. However, with little additional effort, many other performance measures could be obtained.

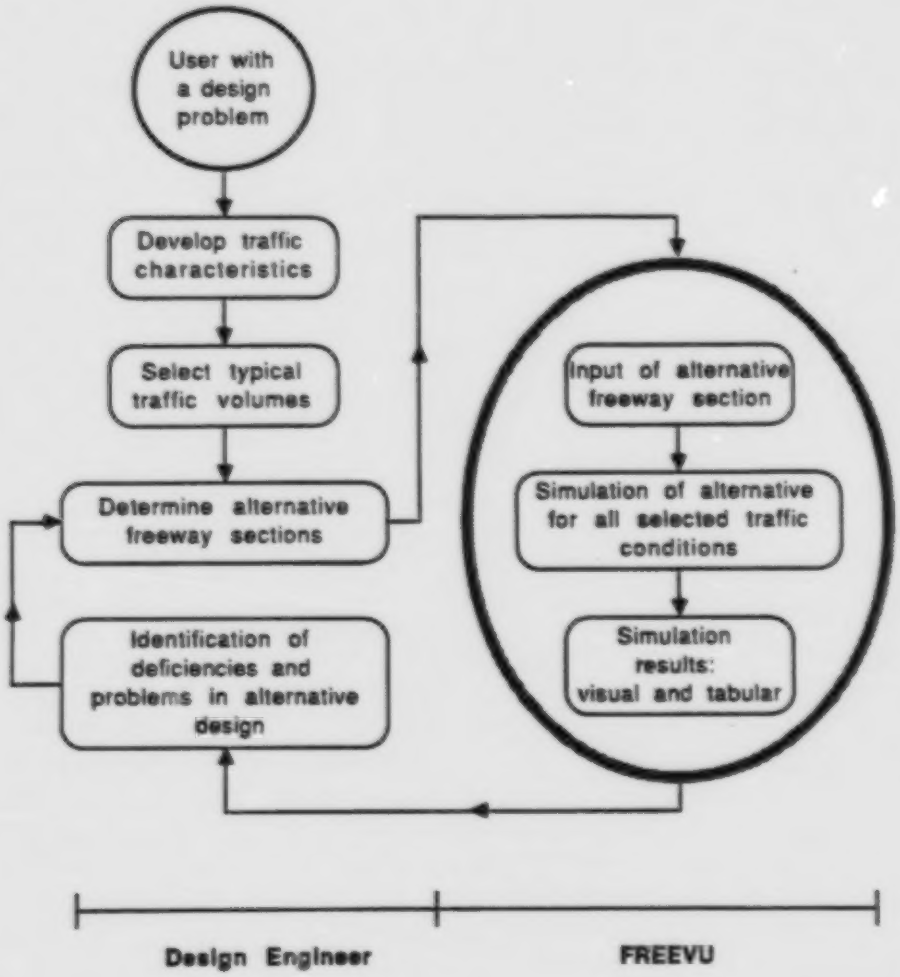

User with a design problem
Develop traffic characteristics
Select typical traffic volumes
Determine alternative freeway sections
Identification of deficiencies and problems in alternative design
Input of alternative freeway section
Simulation of alternative for all selected traffic conditions
Simulation results: visual and tabular
Design Engineer
FREEVU

Figure 3.4: Designer — model environment

Chapter 4

FREEVU — the model

The previous three chapters have described the role of a freeway traffic simulation model, as well as identified the components of the freeway system that must be reflected by the model. This chapter describes the model — its goals, structure, data requirements, input sequence, output options and limitations. Specific details related to the modelling of individual components are discussed in Chapter 5.

The goal in developing FREEVU was to create a model which, in order to be effective, would have the following four characteristics:

1. Easy to use.
2. Reflect reality.
3. Provide useful output.
4. Enhance the user's understanding of flow performance over the freeway section.

Each characteristic is reflected in the structure of FREEVU. As illustrated in Figure 4.1, FREEVU consists of four distinct program modules, each performing a specific function. Three of these four modules are part of the integrated design shell which makes the program easy to use and enhances the user's understanding. The fourth module is the simulator, derived from FOMIS, and is responsible to reflecting reality and providing useful output.

In the design shell, the user has access to two of the modules, Freeway Specification and Traffic Performance. The third interface module translates the data, input by the user, into the correct format required by the simulator. This translation phase is invisible to the user, but permits data input to be tailored to a format which is

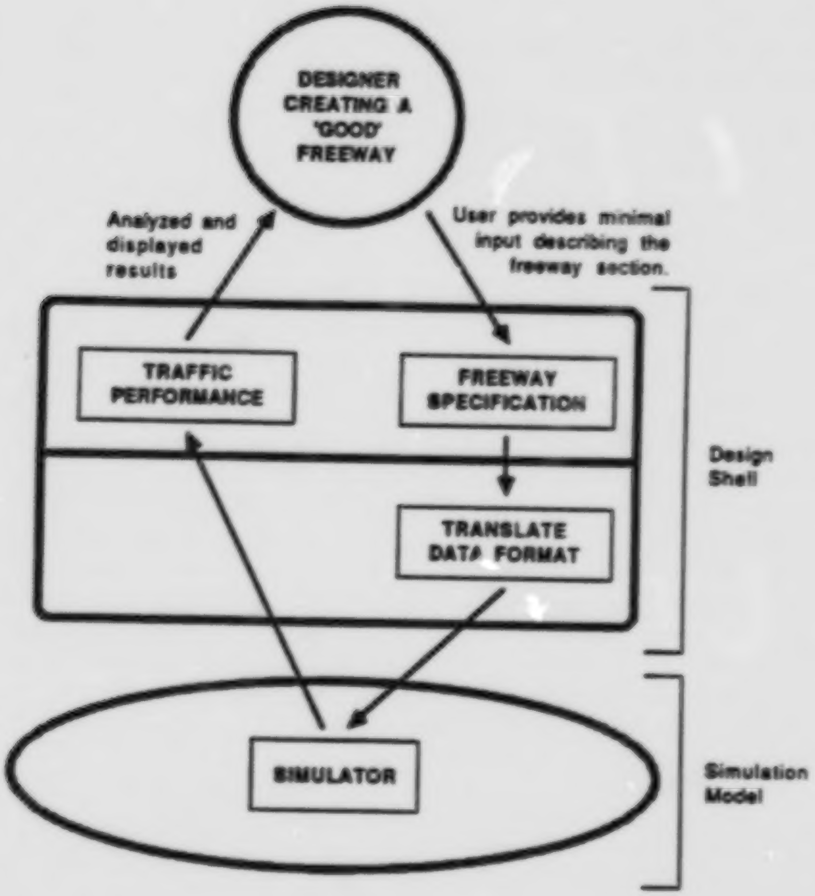

DESIGNER CREATING A 'GOOD' FREEWAY
Analyzed and displayed results
User provides minimal input describing the freeway section.
TRAFFIC PERFORMANCE
FREEWAY SPECIFICATION
TRANSLATE DATA FORMAT
Design Shell
SIMULATOR
Simulation Model

Figure 4.1: FREEVU – modular structure

simple and logical for the user, while also ensuring a complete and efficient format for the simulator.

The amount of program code developed for each module is approximately the same, with the design shell comprising slightly more than 75% of the whole program. The most complex module of the design shell is the translation module as it must conduct error trapping and logically determine all aspects of the freeway section from minimal user input. Much effort was invested into the design and structuring of the design shell as, without a clear and easy to understand interface, the design tool would not be used, regardless of how accurate and versatile the simulation core may be.

The program's interface structure was constructed around the common menu. This approach was thought to provide a simple, familiar, easy to understand appearance to the user with the minimum of complex program code. The structure consists of a menu tree, with each menu presenting the user with a number of possible alternatives (Figure 4.2).

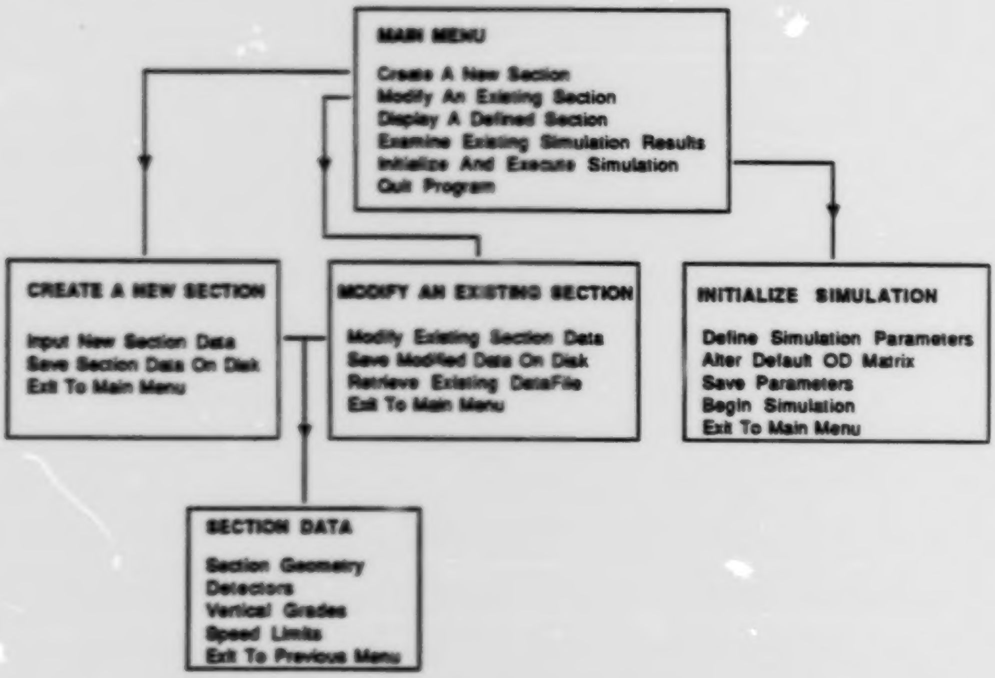

MAIN MENU
Create A New Section
Modify An Existing Section
Display A Defined Section
Examine Existing Simulation Results
Initialize And Execute Simulation
Quit Program
CREATE A NEW SECTION
Input New Section Data
Save Section Data On Disk
Exit To Main Menu
MODIFY AN EXISTING SECTION
Modify Existing Section Data
Save Modified Data On Disk
Retrieve Existing DataFile
Exit To Main Menu
INITIALIZE SIMULATION
Define Simulation Parameters
Alter Default OD Matrix
Save Parameters
Begin Simulation
Exit To Main Menu
SECTION DATA
Section Geometry
Detectors
Vertical Grades
Speed Limits
Exit To Previous Menu

Figure 4.2: FREEVU menu structure

The complete menu structure consists of five menus, operating on three interaction levels:

MAIN MENU providing primary access to the second level menu options as well as the option to quit.

CREATE A NEW SECTION controls the process of entering and saving the data required to define a freeway segment.

MODIFY AN EXISTING SECTION is similar to the CREATE A NEW SECTION menu except that the user may retrieve existing data from the disk.

INITIALIZE SIMULATION controls input of simulation data as well as selection of output files.

SECTION DATA is the only 3rd level menu. It permits the user to directly input data describing the freeway section geometry.

Data input is highly structured and controlled by internal checking routines. The user is informed of the data required and only permitted to enter data of the specified type (i.e. integer, alphabetic) and within specific ranges dependent on previous input. Speed of input is facilitated by default values given when possible, allowing the user to simply accept the values and move on to the next input cell. Logical errors in the user definition of the freeway section are checked, and if found, the user is informed and given the opportunity to modify the data. The user is able to exit from any menu or data entry operation and return to the next higher level.

The remainder of this chapter investigates and discusses each module of FREEVU in turn, following the order — Freeway Specification, Simulation,Translation and Traffic Performance.

A tutorial is located in the User's Manual found in Appendix C. A diskette containing the program and a demonstration is included with this report.

4.1 Freeway specification module

Of the six MAIN MENU options illustrated in Figure 4.2, three deal with data input, one with viewing results, one with initializing and executing the simulation, and the last with terminating the program.

The three menu options dealing with data input are:

- CREATE A NEW SECTION
- MODIFY AN EXISTING SECTION
- DISPLAY A DEFINED SECTION

The purpose of these three menu options is to allow the user to input data as easily as possible, and then to be able to verify that the data is correct by directly viewing the section. The user can define a new section, or if only modifications are required, can simply make the necessary corrections to the existing data. Having defined a section, it can be displayed on the screen in either a scaled plan or profile view. All entrances, exits and detector locations are shown and numbered. This visual feedback allows the user to immediately decide if the section is defined as desired, without having to tediously examine numerical output.

Creating and modifying data is done using the same data entry forms available via the SECTION DATA menu. When modifying data, the data to be modified must first be retrieved from disk, and can be modified in any order. When creating a new section, a specific data input sequence is followed based on the four data input categories available;

1. Section geometry
2. Detector locations
3. Vertical curvature
4. Posted speed limits

The user is prompted to provide the various data required in the order indicated in Figure 4.3.

FREEVU represents freeway sections linearly, and as such all locational data is taken as the distance, in metres, along the centre line from the upstream boundary. The upstream boundary is the upstream end of the simulated section where vehicles are generated. No data is required concerning horizontal alignment [1] since horizontal curvature is not modelled.

To illustrate, consider the freeway section in Figure 4.4. Linearizing the section to be modelled and representing it schematically causes the section to appear as in Figure 4.5. Note that all the locational data is defined as the distance from the upstream boundary of the simulated section. The upstream section boundary is considered to be the origin point.

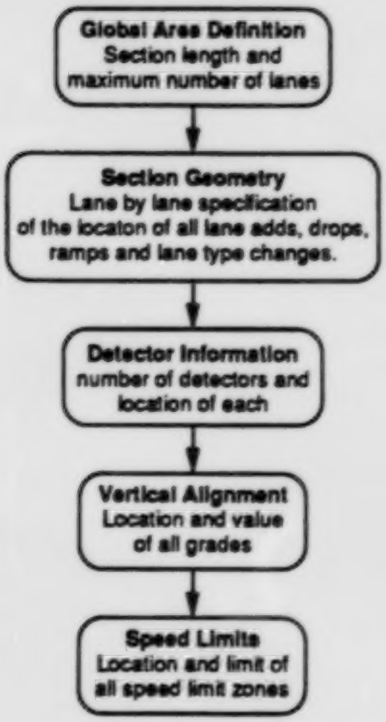

Global Area Definition
Section length and maximum number of lanes
Section Geometry
Lane by lane specification of the locaton of all lane adds, drops, ramps and lane type changes.
Detector Information
number of detectors and location of each
Vertical Alignment
Location and value of all grades
Speed Limits
Location and limit of all speed limit zones

Figure 4.3: Data requirements and input order

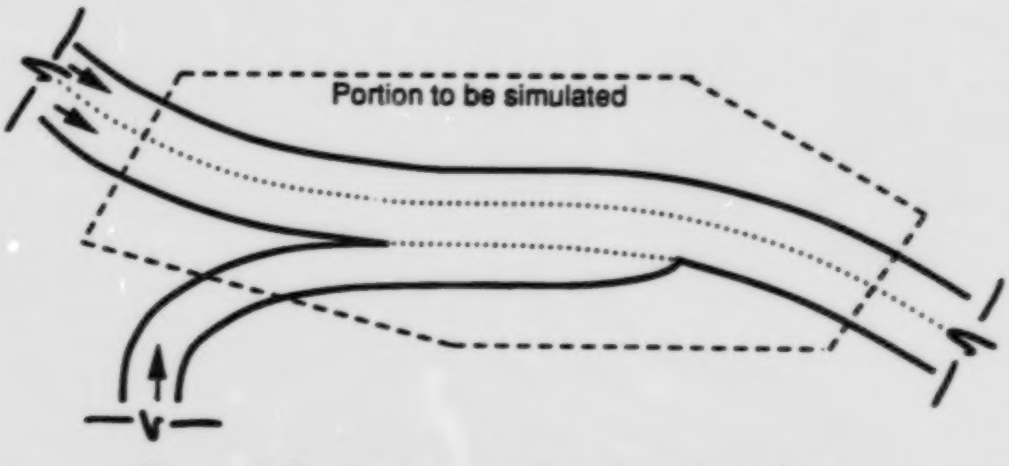

Portion to be simulated

Figure 4.4: Freeway segment and portion to be modelled

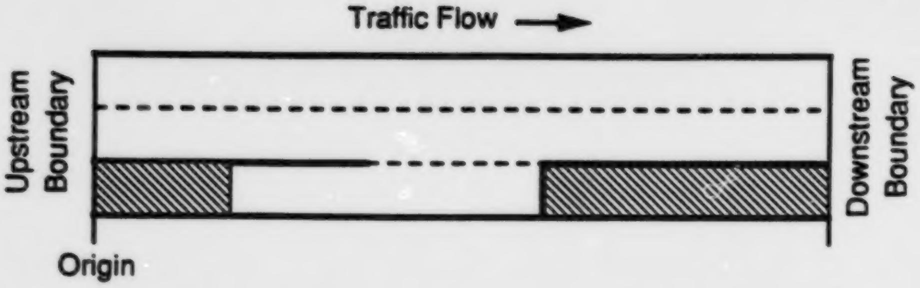


Figure 4.5: Schematically represented section to be modelled

Transforming the freeway section from the standard plan format to a schematic representation enables the user to have all the required data represented in a convenient form for input to FREEVU. Note that information regarding grades is not indicated on the plan view. FREEVU input requires that the profile of each lane in the section be defined to the nearest integer percent grade.

Entering the data is straight forward. All numeric data must be in integer format. For most input requiring a numeric input, a default value will appear in the input cell. The user can choose to accept this value or input a new value using the keyboard.

When all data has been correctly input, the user must save the input data to disk in order to subsequently run the simulation. If the user makes errors in defining the section, such that the data describes a section which is not physically possible (i.e. a centre lane with no lane to the right, or the entire freeway section is not defined), an error message will appear when the user attempts to save the data to disk. At this point the user should return to the appropriate data input menu and correct the problem. Error messages and correcting errors are described more fully in the User's Manual found in Appendix C.

4.1.1 Section geometry

The user is required to input the total length, in metres, of the section to be modelled, and the maximum number of lanes. The maximum section length is 10,000 metres and the maximum number of lanes is 8.

---

[1] If horizontal curvature significantly affects speed, then this can be reflected via posted speed limit (see Section 5.4).

Having defined the area of the section , all the features of the section must be defined for each lane using the input form shown in Figure 4.6.

Lane	Segment	From (m)	To (m)	Physical Feature	Lane Type
1	1	0	▬	▬	▬

Figure 4.6: Section Geometry data input form

The shaded boxes in Figure 4.6 indicate where user input is required. Each of the column headings is explained below:

Lane The lane number currently being defined. Lanes are numbered consecutively from the median lane to the shoulder lane.

Segment Segments are lengths of lane *homogeneous* in terms of lane type. Segments are numbered consecutively from the upstream end to the downstream end of the freeway section with a maximum of 15 segments permitted in any one lane.

From The location, in metres, of the upstream end of the current segment, measured from the upstream boundary of the simulated freeway section.

To The location, in metres, of the downstream edge of the current segment, measured from the upstream boundary of the simulated section.

Physical Feature Any geometric change occurring in the current lane, which defines the upstream boundary of the current segment. Permissible features (Table 4.1) are selected from a menu.

Lane Type The lane type of the current segment. Permissible lane types (Table 4.1) are chosen from a menu.

The critical issue for correct geometry data input is the understanding of what a *segment* is and how one is defined. A segment is a length of lane *homogeneous* in terms of lane type. This means that any given segment will contain only one lane type, be it a centre lane or one of the other permissible choices. A segment also has some physical feature located at its upstream boundary. This physical feature may be some geometric change in the lane (i.e. off ramp end) or it may simply be that the

Table 4.1: Permissible Physical Features and Lane Types

Physical Features	Lane Types
Lane Drop	Centre
Lane Add	Right
Off Ramp End	Left
On Ramp Start	Only
System Start	None[1]
Lane Type Change	
Bull Nose	

[1] Not a traffic lane

lane type has changed due to some geometric change in the freeway section at that point, outside of the current lane (i.e. changing from the right lane to a centre lane due to the presence of an adjacent deceleration lane as illustrated in Figure 4.7).

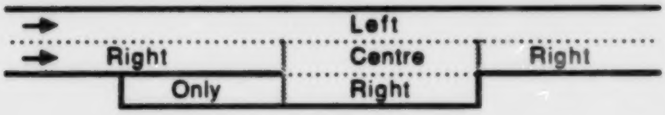


Figure 4.7: Example of a lane type change due to a geometric change outside of the current lane

Only one physical feature may be coded at any given location along the freeway section regardless of the number of lanes. This restriction does not apply to the physical feature Lane Type Change. For example, it is permissible to specify a Lane Drop physical feature in a different lane, but at the same location along the section, as a Lane Type Change feature, as is done in Figure 4.7 at the point where the acceleration lane ends. However, it is not permissible to have defined, for example, a Lane Add feature in the median lane at the same location as the Lane Drop.

To help prevent the user from inputting incorrect data, FREEVU will not allow invalid lane types and physical features to be selected, however, care should still be exercised to ensure that the freeway section geometry is accurately defined.

A detailed tutorial is presented in the User's Manual located in Appendix C.

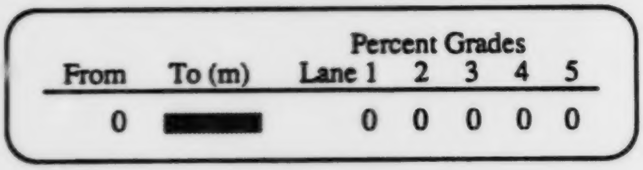
4.1.2 Detectors

The detectors provided in FREEVU represent paired induction loop detectors and can be placed at any location along the freeway section being modelled. Defining a detector location places detector loops in all traffic lanes across the freeway section at that point.

FREEVU will prompt the user to indicate the number of detector locations desired. The maximum number of locations is 20. Having indicated the number of detector locations desired, a data input screen appears prompting the user to define the location of each detector group in terms of its distance in metres from the upstream freeway section boundary.

4.1.3 Vertical grades

The profile of the freeway section is defined using the data input form shown in Figure 4.8. In defining vertical grades, segments of the freeway having a consistent grade, are defined. Each lane of the freeway may have a unique grade defined for each of the defined segments. Note that the homogeneous segments defined here are not related to those defined when describing the geometry of the freeway. This permits maximum flexibility for the user when defining the freeway section.



		Percent Grades				
From	To (m)	Lane 1	2	3	4	5
0		0	0	0	0	0

Figure 4.8: Grade specification input screen

Grades must be expressed as an *integer* percentage. There are two reasons for permitting grades to be input as whole numbers only;

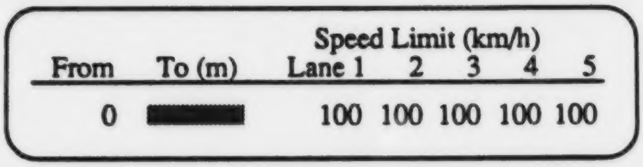
- data input is easier as only the general profile need be input.
- minor changes in grade have little effect on traffic performance.

The specification of homogeneous grade segments is similar to that described earlier for section geometry, except that the defined segment applies to all lanes. To aid in the entry of the percent grades, lane 1 (the median lane) acts as a *global* control for all lanes. Thus if lane 1 is defined as having a vertical grade of 3% for some segment, then all lanes within this segment also have a 3% grade. If this is not desired, the user simply moves the cursor to the lane which requires modification, and enters a new percent grade.

The maximum number of grade segments which can be specified is 20. The default grade assigned to the entire freeway section is 0% grade. The steepest upgrade that can be specified is 10% and the steepest downgrade, -10%.

4.1.4 Speed limits

The entry of speed limits proceeds exactly as for the definition of grades. The input screen (Figure 4.9) is similar and data entry is the same. In this case, segments are portions of the freeway having the same posted speed limit. Permissible speed limits range from 40 km/h to 120 km/h.



From	To (m)	Speed Limit (km/h) Lane 1	2	3	4	5
0	▬	100	100	100	100	100

Figure 4.9: Speed limit input screen

The primary purpose of allowing the user to define speed limits is to enable the model to more realistically reflect the effects of reduced speeds of vehicles traversing ramp sections. However, speed limits can also be used to reflect other factors which affect speed and can not be explicitly modelled using FREEVU. For example, if a section of the freeway has very poor pavement surface conditions, one may wish to designate this area as having a posted speed limit of 90 km/h to reflect the effect the poor surface has on speed. Other applications for this artificial posted speed include narrow lane widths, horizontal curves, and areas of poor visibility.

The effect that posted speed limit has on driver's free speeds is described in detail in Section 5.3.

4.1.5 Data input summary

The user is required to input data on section geometry, detector locations, vertical alignment, and posted speed limits, for each freeway section. Three independent types of segments are defined;

1. Lane segments for defining section geometry.
2. Vertical curvature segments.
3. Posted speed limit zone segments.

Figure 4.10 illustrates how these segment types are independent of each other and are layered to define the characteristics of the freeway section. Each segment is depicted as having a different fill pattern than adjacent segments. It should be noted that Geometric segments are specific to each individual lane, while both Vertical Alignment and Speed Limit segments apply to all lanes, though unique values can be assigned to each lane within the segment. The areas shaded black represent areas which are not traffic lanes. When the user defines the section geometry, these areas are designated as non-traffic lanes. For both the vertical alignment and posted speed limit data input, however, some value must be assigned for these segments, even though it will have no effect on the simulation results as no traffic travels on these segments.

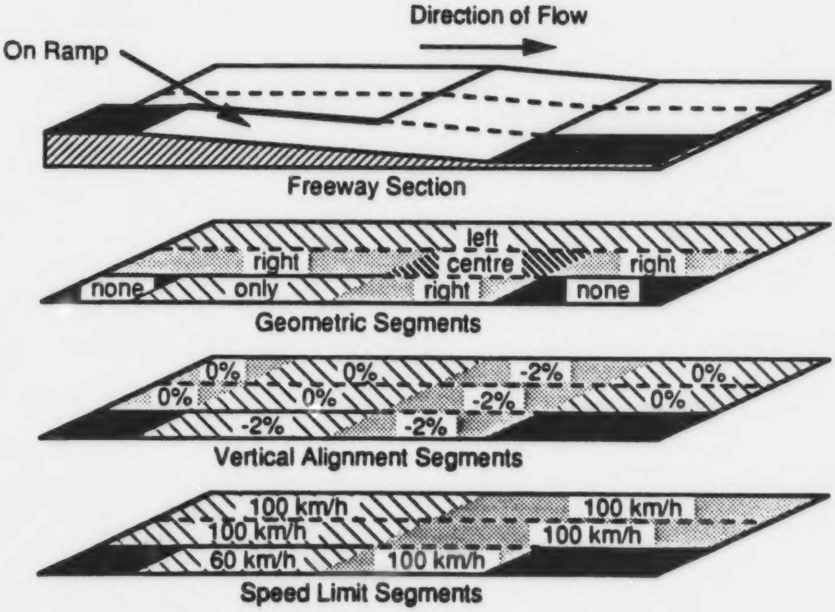

Direction of Flow
On Ramp
Freeway Section
left
right
centre
right
none
only
right
none
Geometric Segments
0%
0%
-2%
0%
0%
0%
-2%
0%
-2%
-2%
Vertical Alignment Segments
100 km/h
100 km/h
100 km/h
100 km/h
60 km/h
100 km/h
Speed Limit Segments

Figure 4.10: Three segment types used to define a freeway section

4.1.6 Displaying a section

Having defined a freeway section and saved it to disk the user can display the section to ensure that the data entered, correctly describes the freeway section to be modelled.

The program allows the user to select one of the sections previously defined and stored on disk. A scaled plan view of the entire section is initially displayed with detector locations and entrances and exits indicated. Detector locations are indicated with small yellow boxes; entrances, where vehicles are generated, are indicated by a vertical red line; and exits are indicated by a vertical magenta line. Each detector location, entrance and exit is numbered to allow the user to correlate output to the appropriate item.

The user is able to manipulate the display in a number of ways. Options available to the user are presented and described in Table 4.2.

Table 4.2: User options when displaying section

Option	Key	Description
Zoom[1]	`F1`	View only a portion of section
Profile/Plan	`F2`	Toggle between plan view and profile
View Entire	`E`	View entire section
Quit Display	`Esc`	Return to main menu

[1] sections shorter than 1 km can not be *Zoomed*.

If the user elects to *zoom* in on a portion of the freeway section, another set of options, presented in Table 4.3, become available within the *zoom* mode.

If any discrepancies exist between the displayed freeway section and the freeway section the user attempted to define, modifications can be made using the MODIFY EXISTING SECTION menu.

4.2 Simulation module

This module carries out the microscopic simulation of individual vehicles over the user defined freeway section.

Vehicle and driver behaviour is modelled by car-following and lane-changing algorithms. The car following algorithms are essentially unchanged from FOMIS and

Table 4.3: User options when zooming

Option	Key	Description
View Entire	Esc	View entire section
Redraw	Return	Redraw selected portion
Enlarge	↑	Enlarge selected area to view
Shrink[1]	↓	Reduce the size of selected area
Left	←	Move selected area to left
Right	→	Move selected area to right

[1] sections shorter than 1 km can not be *Zoomed*.

INTRAS, however lane changing algorithms have been implemented to more closely reflect driver decision logic and the concept of driver self-interest. These algorithms are fully described in Chapter 5.

Within this module, the freeway segment is structured as a single continuous unit, with elements (i.e. vehicles or fixed objects) located by their distance from the downstream boundary and the lane number (Figure 4.11). Fixed objects are used to define the geometry and characteristics of the section, including lane adds and drops, on and off ramps from either the left or right side of the freeway, weaving sections, speed limits, grades, and detector locations.

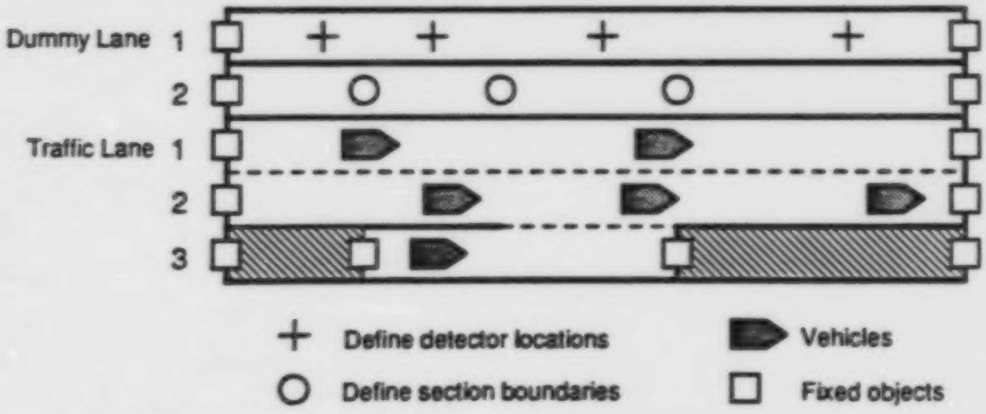


Figure 4.11: Freeway section representation internal to the simulator

Vehicles are processed in order of their location, regardless of lane, from downstream to upstream. A single pass is made for each time interval, during which, each vehicle is processed. Processing a vehicle includes car following, lane changing, and collision avoidance algorithms.

During every time interval, the location of the next upstream and downstream object, either a fixed or vehicle object, is known for each object. This format must be created for the simulator from the user input data in order to define the fixed objects, their locations, and characteristics.

The basic structure of the simulation module has remained unchanged from FOMIS, however, a number of major enhancements have been made to make it more reflective of reality. These enhancements are reflective of those components of the freeway system determined in Chapter 2 to be important for their effect on traffic flow.

- Incorporated the ability to model grades to reflect the effect on vehicle speeds, particularly truck speeds.
- Introduced attainable acceleration as a function of speed, grade, and vehicle characteristics to reflect the limitations vehicle characteristics may dictate, particularly for loaded trucks on grades.
- "Normal" acceleration was introduced to prevent unrealistically extreme acceleration behaviour.
- Vehicle generation was modified to produce a traffic stream which followed a shifted negative exponential headway distribution.
- Lane changing algorithms were introduced, incorporating driver characteristics, traffic conditions, vehicle type, and vehicle's current speed, in order to model the effect of driver's self-interest on lane changes.
- Vehicle types defined by the user originally all had an equal probability of occurring in the traffic stream. This was altered to permit each vehicle type a unique probability of occurring so that a representative vehicle population can be defined.
- Introduced posted speed limit to control the overall speed of the traffic stream, particularly for sections of the freeway with restricted speed limits, such as ramps.
- Incorporated the ability to generate different volumes over time in order to effectively reflect peak period growth and decline within a single simulation run.

Despite these enhancements, FREEVU does not explicitly model all factors affecting traffic flow. Following is a list of those parameters or events which can not be explicitly modelled.

- lane width
- horizontal curvature
- passing sight distance
- weather
- road surface conditions
- incidents
- "rubber necking"

Though these can not be modelled explicitly by FREEVU, many of these effects can be simulated by specifying a reduced speed limit for the affected lane and section. In this manner, speed can act as a surrogate means for simulating these other effects. For example, if the analysis is to examine traffic flow under adverse weather conditions the posted speed limit for all lanes could be specified as 85 km/h instead of the standard 100 km/h. Obviously some understanding of the expected result of the event is needed in order to realistically apply the speed limit as a surrogate control.

Program details for the simulation module , including its structure, subroutine descriptions, and a source code listing appear in Appendix B.

4.3 Translation module

This module is hidden from the user, but exists as the vital link between the user friendly exterior of the program and the simulator core.

The primary objective of this module is to translate the data from the user input format, consisting of different segment types, into the simulator format, and check for data input errors.

The module converts all user input data into a format representing physical features as fixed objects. These objects are ordered and placed in their correct locations on the freeway section. Based on the user input, all possible entrance-exit paths are identified and a default origin-destination matrix is determined. All entrances, exits and detectors are identified, ordered, numbered, and denoted with a fixed object.

A detailed documentation of the program code is not provided as there are many explanatory remarks within the source code. Variables are described within each procedure. Intermediate results produced by the translation procedures can be viewed on the screen by changing the boolean variable `Echo` from `False` to `True`, in the procedure `Translate` in the unit `Translation`, and recompiling the program.

4.4 Traffic performance

FREEVU provides the user with two types of output — formatted output written to the disk and on-screen output. The output written to the disk, which can be subsequently printed, consists of typical measures of performance. The on-screen output consists of a *movie* of the freeway which can be viewed. Each of these two forms of output is discussed in detail in the following sections.

4.4.1 Animation

One of the key features of FREEVU is the "movie" feature. This feature allows for instant visual feed back to the designer about the microscopic level of interaction occurring on the freeway. This ability greatly enhances the understanding of the macroscopic measures of effectiveness obtained from aggregated detector output.

This feature is also useful for understanding the actual direct effects of any control strategies implemented (i.e. extension of acceleration lanes). At the development level, this feature was very useful for debugging of the program. Macroscopic measures simply negate too much of the dynamic detail of the vehicle interactions to provide effective feedback for debugging purposes.

When the *movie* feature is initiated, the freeway section will be displayed in plan view and the user can *zoom* in on a portion of the freeway section before beginning the *movie*.

Once the animation is begun the user has a number of options with which to control the speed at which the vehicles move, and what measures of performance are displayed (Table 4.4).

When Pause is selected, the user can step through the animation one second at a time by hitting {`Return`} for each time step. This permits total control over the movie speed. The user can restart the movie by entering `P` again.

Table 4.4: User options when watching animation

Option	Key	Description
Quit	Esc	Return to the main menu
Pause	P	Pause the movie
Speed Up	↑	Speed up movie
Slow Down	↓	Reduce the speed of movie
Dtcr Info	D	alter the displayed detector info

The detector information available is average volume, speed and density. These values apply to the previously recorded 30 seconds of traffic flow. The values appear directly above the detector location to which they apply. The loop detectors appear as dark gray squares centred in the lane. The detector information is only updated on the screen at the end of each 30 second detector recording interval. Therefore, when the animation first begins, no data will be displayed until 30 seconds have elapsed.

The display scales the selected section to fit on the screen, however the lane width is fixed. Vehicles are represented as red rectangles with a length scaled to the same scale as used to display the section. Similarly, trucks are represented to scale as yellow rectangles. When vehicles change lanes they are displayed in white.

This display mode is extremely useful to gain an immediate *understanding* of how well the freeway is operating. This feature prompted the name FREEVU, FREeway Evaluation with Visual Understanding. Visually, one can immediately identify queues forming, platoons existing behind slow trucks, effects of lane changes, and the amount of disruption in the vicinity of merging areas. All of this is apparent from the ability to view the vehicles. In addition, standard detector output provides quantitative data to the user.

4.4.2 Numerical output

Complimenting the visual output provided by the animation feature, hard output is also produced by FREEVU. Currently four output files can be generated, each providing different information on the performance of the freeway section and quality of traffic flow.

1. Standard detector information — speed, volume and density for a user specified time period.

2. Record of the number and type of lane changes that occurred during the simulation. The user can choose to produce a summary of the lane changes, or the complete record of each lane change that occurred.
3. Record of the number and type of manoeuvres by vehicle class, made during the simulation. The following manoeuvre types are recorded:
    - (a) Pass on the left to increase speed
    - (b) Pass on the right to increase speed
    - (c) Yield to the right because vehicle can not maintain current speed
    - (d) Desired lane change
    - (e) Mandatory lane change
    - (f) Yield to the right because vehicle is blocking a faster vehicle behind it
    - (g) Vehicle is decelerating at a rate which is greater than normal deceleration

    Lane change types are explained fully in Section 5.4.
4. The average travel times, in seconds, for each origin-destination pair for cars and trucks. The standard deviation and number of vehicles observed is also given.

The output files presented here have been created to satisfy needs arising during model development and evaluation, however, with minor alterations and additions to the program code, almost any type of output can be created. It is expected that as design experience with FREEVU is obtained, the output will be refined.

4.5 Program limitations

Due to computer hardware and software limitations, the restrictions presented in Table 4.5 have currently been selected for FREEVU.

Table 4.5: Restrictions applicable to FREEVU

Item	Maximum # Permitted
Section length	10 km
Traffic lanes	8
Entrances, including on ramps	20
Exits	20
Detector locations	20
Geometric segments	15
Speed limit zones	20
Vertical alignment segments	20
Different vehicle types	100
Vehicles on section at one time	2500

4.6 Summary

In Chapter 1, FOMIS was evaluated and found to be difficult to understand, difficult to control and apply, and not complete and accurate on important items. As a result, the FOMIS model was enhanced and modified to produce the model FREEVU.

FREEVU is simple to understand and easy for the user to control and apply due to an extensive, user-friendly interface created to surround the simulation core. All data entry is conducted using interactive menus with logical error trapping and default values. A "movie" feature was incorporated to enhance the user's understanding of the microscopic dynamic flow characteristics of the traffic stream. The capability to display the defined freeway section on the screen in either a scaled plan or profile view provides immediate feedback to the user regarding the accuracy of the input data.

Many features of the freeway system previously not modelled have been incorporated into FREEVU including grades, posted speed limits, different vehicle types, and lane changing algorithms. The incorporated features are described in detail in the next chapter.

Chapter 5

Key algorithms and assumptions

Chapter 4 described the characteristics of FREEVU and indicated the components of the freeway system modelled. This chapter explains in detail the manner in which these components are modelled.

5.1 Car following theory

The car following model implemented in FREEVU is essentially unchanged from the model used in INTRAS. The derivation of the car following model is presented here briefly, in order to provide the reader with an understanding of the theoretical basis, however, it should be noted that this discussion is based on available INTRAS documentation [40], not on the author's own derivations or work.

The basic car following model is based on the underlying assumption that drivers will attempt to maintain some spatial headway as a function of the driver's own characteristics, the speed of the leading and following vehicle, and the length of the leading vehicle (Figure 5.1 and Equation 5.1).

$$h_s = L + kv_2 + 10 + bk(v_1 - v_2)^2 \tag{5.1}$$

Where h_s is the space headway desired; L is the length of the leading vehicle; k is the car following parameter; b is a constant that controls the sensitivity to oscillating; v_1 and v_2 are the velocities at time t, of the leading and following vehicle.

The leading vehicle's velocity (v_1^*) and position (x_1^*) are known for time $t + T$, and the following vehicle's speed (v_2) and position (x_2) are known for time t. It is necessary to determine the acceleration of the following vehicle, a.

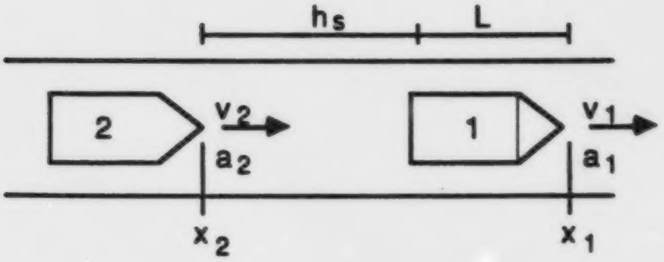


Figure 5.1: Car following theory

The desired location for the following vehicle at time $t + T$ can be determined from Equation 5.2.

$$x_1^* - x_2^* = L + 10 + kv_2^* + bk(v_1^* - v_2^*)^2 \tag{5.2}$$

From the fundamental laws of motion, for constant acceleration, the position of vehicle 2 at time $t + T$ can be determined.

$$x_2^* = x_2 + v_2T + \frac{aT^2}{2} \tag{5.3}$$

Likewise, the velocity at time $t + T$ can be calculated.

$$v_2^* = v_2 + aT \tag{5.4}$$

Substituting Equations 5.3 and 5.4 into Equation 5.2;

$$x_1^* - (x_2 + v_2T + \frac{aT^2}{2}) = L + 10 + k(v_2 + aT) + bk(v_1^* - v_2^*)^2 \tag{5.5}$$

It is assumed that the term $(v_1^* - v_2^*)^2$ is small and as such, the approximation that $v_2^* = v_2$ can be made without introducing any significant error. Any error introduced here is negated through the calibration of the constant b. This assumption is made to avoid the necessity of solving a rather complex quadratic equation for a.

The basic car following relationship is;

$$a = 2[x_1^* - x_2 - L - 10 - v_2(T + k) - bk(v_1^* - v_2)^2]/(T^2 - 2kT) \tag{5.6}$$

The constant b acts as a dampening factor on the oscillating of vehicle speeds as the vehicle attempts to maintain its desired spatial headway. The value of b was determined during calibration of INTRAS [51];

$$b = \begin{cases} 0.1 & \text{if } (v_1^* - v_2) \leq 3.05 \text{ m/s } (11.0 \text{ km/h}) \\ 0 & \text{otherwise} \end{cases}$$

A driver reaction time c is introduced when calculating the new speed and position of the following vehicle.

$$v_2^* = v_2 + a(T - c)x_2^* = x_2 + v_2 T + \frac{a(T - c)^2}{2} \tag{5.7}$$

where c, having units of seconds, must be $< T$.

Again, c was determined during calibration of INTRAS;

$$c = \begin{cases} 0.2 & \text{if } a^{t-1} > 0.123 \text{ m/s}^2 \ (0.44 \text{ km/h/s}) \\ 0.3 & \text{if } 0 < a^t \leq 0.914 \text{ m/s}^2 \ (3.3 \text{ km/h/s}) \\ 0 & \text{otherwise} \end{cases}$$

where t represents the current time interval.

In addition to the derived car following relationship, an emergency constraint exists which overrides the basic car following algorithm in order to prevent collisions. Again, this constraint is the same as that developed for INTRAS. As the development of this emergency constraint is rather lengthy, it will not be presented here, however a full derivation is presented in published INTRAS documentation [50].

Basically the constraint provides that the following vehicle can maintain a safe headway under the following two conditions;

1. the leading vehicle decelerates at maximum emergency deceleration.
2. given that there exists a driver reaction time c, the following vehicle can maintain a safe headway by applying a deceleration rate which is within the emergency deceleration rate limit.

5.1.1 Effect of driver characteristic k

The parameter k attempts to capture the variations in driver characteristics that influence driver behaviour. Simply stated, k reflects the aggressiveness of an individual

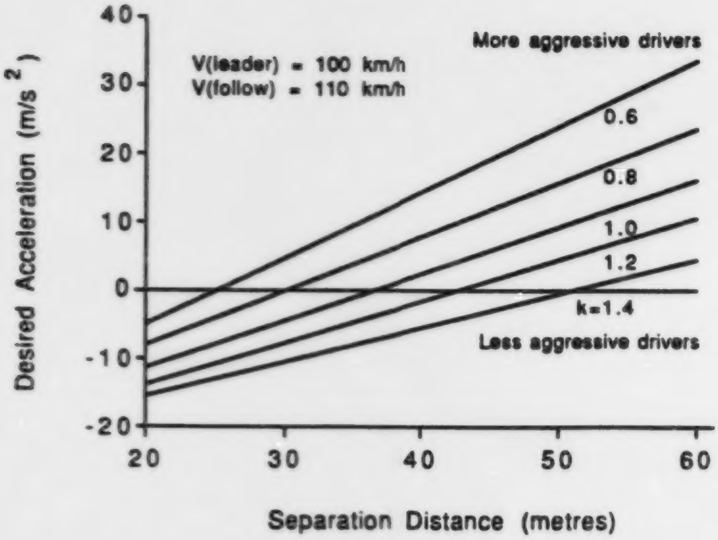


Figure 5.2: Effect of driver characteristic k on acceleration

driver. The function influences the space headway drivers consider desirable. For example, aggressive drivers will accept a shorter space headway for a given situation, than will less aggressive drivers. Figure 5.2 depicts the effect of k on acceleration.

Since k controls drivers' desired space headway, it also controls maximum flow. During calibration of INTRAS, k was determined to be 0.93. The rationale was that the maximum flow for a car only stream should be approximately 2000 vphpl. However, it was discovered that driver sensitivity can vary significantly. This is discussed in greater detail in Chapter 6.

5.2 Vehicle generation

Since only a portion of the transportation network is being considered during simulation, there exists artificial boundaries through which flow is generated and terminated. These boundaries occur at the upstream and downstream ends of the freeway section being considered. As well, boundaries occur at on-ramps upstream of the freeway merge, and at off-ramps downstream of the freeway exit. For all upstream boundaries, vehicles must be artificially generated to create a traffic stream. At all downstream boundaries vehicles are simply deleted from further consideration.

Assuming that the arrival times of freeway traffic passing a point can be described by a Poisson distribution, then it can be shown that the distribution of inter-arrival times conforms to a negative exponential distribution of the form [47];

$$P(h < t) = e^{-qt} \tag{5.8}$$

where h is the time headway; t is some time; and q is the average arrival rate for the specified volume of traffic at the entrance lane.

Since vehicles possess a length it is not possible for a vehicle to follow at some very small headway. To avoid this, the distribution can be shifted to the right by some time τ, reflecting that a practical minimum headway exists.

$$P(h < t) = e^{-(t-\tau)/(\bar{t}-\tau)} \tag{5.9}$$

where $\bar{t}$ the mean time headway equals $1/q$.

Expressing Equation 5.9 explicitly in terms of time t;

$$t = \tau - \ln(P(h < t))(\bar{t} - \tau) \tag{5.10}$$

Since $P(h < t)$ is a uniformly distributed random variable, it becomes rather simple to generate random time headways that follow a shifted negative exponential distribution.

The critical gap length has been assumed to vary linearly with desired volume (V_d) with a minimum gap length of 0.8 seconds. The gap length can be determined from:

$$\tau = \begin{cases} 0.5 + 0.00055V_d & \text{if } V_d \geq 545 \text{ vph} \\ 0.8 & \text{if } V_d < 545 \text{ vph} \end{cases}$$

Having τ defined as above results in produced volumes closely reflecting desired volumes as indicated in Table 5.1.

Having determined a time headway, an equivalent space headway is calculated based on the speed of the downstream vehicle in the current lane. The generated vehicle is placed a distance $(h_s - L)$ behind the rear of the downstream vehicle.

It should be noted that there remains some variation of actual generated volumes about the user specified desired volume, though the variation is observed to be normally within 10% of the desired volumes. This is due largely to the random nature of FREEVU, and also to the rather short simulation times usually analyzed (typically simulation runs will not exceed 30 minutes of simulated real time).

Table 5.1: Comparison of Desired and Produced Volumes

Desired Volume	Produced Volume	Error (%)	Simulation Time (min)	τ (sec)
250	256	2.4	15	0.80
500	485	-3.0	15	0.80
750	804	7.2	10	0.91
1000	1008	0.8	10	1.05
1250	1284	2.7	5	1.19
1500	1424	-5.1	5	1.33
1750	1676	-4.2	5	1.46
2000	1976	-1.2	5	1.60

Produced volumes based on average of 3 lane volumes.
Three lane tangent section with no grade or ramps and 0% trucks.

After the necessary headway is calculated, a vehicle type is determined. The type is randomly chosen, based on each vehicle type's probability of occurring in the traffic stream. These probabilities are fixed for each vehicle type and specified in the vehicle data file. Thus a fully loaded tractor double trailer combination has a much lower probability of occurring in the traffic stream than does a 50% loaded tractor-single trailer combination. The default vehicle data file, presented in Appendix A, is based on observed truck populations in Ontario [48] and consumer survey information [49].

5.3 Effect of posted speed limit

The implementation of a posted speed limit was originally initiated by the need to more closely reflect ramp environments where reduced speeds are dictated by geometry. These reduced speeds affect on-ramp merging behaviour, particularly for heavily loaded trucks.

It was decided that the implementation of a posted speed limit for areas of the freeway other than ramp sections would also prove beneficial. This posted speed limit could be used to reflect actual posted speed reductions, as well as serve as a surrogate means for dealing with the effects on speed of other situations not explicitly modelled in FREEVU such as;

- poor pavement conditions,

- restrictive geometry,
- rubber necking at an accident location and
- adverse weather conditions.

Obviously, this would require some insight and expertise on the part of the user to determine how large an influence these factors would have on the average speed.

Each vehicle type has some unique *desired* or free speed assigned to it. This free speed is based on the posted speed limit and reflects the maximum speed a driver feels comfortable travelling at. The driver will attempt to travel at this speed, but will not travel at a greater speed, unless the vehicle has just entered an area of reduced speed limit and has not yet adjusted to this. A vehicle may, however, travel at some speed lower than its free speed when forced to by grade effects or interactions with other vehicles (i.e. congestion).

The current default free speed distribution is based on the normal curve, having a mean of 109.5 km/h and standard deviation of 5.3 km/h for a posted speed limit of 100 km/h.

Each vehicle is assigned a normal standard deviate. When the posted speed limit changes, the mean of the distribution of free speeds also changes resulting in a change in the standard deviation. This in turn produces a new desired free speed for each vehicle type.

The free speed of each vehicle is defined by two parameters, and two constants in Equation 5.11.

$$u_{f,i} = u_l \alpha_{\overline{u}_f}(1 + \beta_z z_i) \tag{5.11}$$

where $u_{f,i}$ is the free speed of vehicle type i in km/h, u_l is the posted speed limit in km/h, $\alpha_{\overline{u}_f}$ is a constant relating mean free speed to the posted speed limit and is currently set equal to 1.1, β_z is a constant used to vary the standard deviation as the mean changes and is currently set equal to 0.09, and z_i is the normal standard deviate assigned to vehicle type i.

When a vehicle is generated, its desired or free speed is specified, based on the speed limit of the roadway section in which the vehicle is placed. If the vehicle proceeds into a zone having a higher posted speed limit than previously, the vehicle's desired free speed will increase and the vehicle will attempt to accelerate to attain its new, higher free speed. The maximum acceleration at which a vehicle will accelerate under these circumstances is governed by *comfortable* acceleration rates, expressed in Table 5.2. These *comfortable* rates were obtained from the literature [46], and represent observed acceleration rates at various highway speeds.

Table 5.2: *Comfortable* acceleration and speed transition deceleration rates

Speed Range (km/h)	*Comfortable* Acceleration (m/s^2)	Speed Transition Deceleration (m/s^2)
0 → 24	1.46	1.31
25 → 39	1.46	1.12
40 → 54	1.46	0.97
55 → 69	1.34	0.97
70 → 84	1.07	0.97
85 → 99	0.79	0.97
100 →	0.52	0.97

When a vehicle enters a freeway zone having a reduced posted speed limit it will decelerate to reduce its speed to that of its new free speed based on the new speed limit. This speed transition takes place over some distance as drivers will rarely brake rapidly to reduce their speed, rather they will normally just ease off of the accelerator to cause a gradual transition to their new desired free speed.

In an attempt to characterize this phenomenon, vehicles are assumed to decelerate for speed transition purposes at a rate of 60% of the normal *comfortable* deceleration rates observed for drivers adjusting their speeds downwards [46] (Table 5.2).

It must also be remembered that the approach to speed transitions presented here is only applied to posted speed limits ranging from 60 to 100 km/h as these encompass the normal range of speed limits applicable to freeway systems and their associated ramp junctions.

It is certainly not intended, nor recommended, that this approach be extended to non-freeway situations.

5.4 Lane changing algorithms

The lane change manoeuvres modelled in FREEVU can be classified into two groups;

- Geometry/origin-destination initiated.
- Behavioural/circumstance initiated.

5.4.1 Geometry

This group of lane changes is caused by the interaction of a vehicle's origin and/or destination, and the freeway section geometry. Simply stated, these manoeuvres result from a vehicle originating at some point, desiring to exit at some other point, and due to the freeway geometry, requiring some minimum number of lane changes to reach the destination.

There are two types of geometry initiated lane changes; mandatory and desired.

Mandatory

These are lane changes that are required to be completed within some defined spatial portion of the freeway (i.e. on-ramp merge must occur after the bullnose and before the acceleration lane ends).

FREEVU logic for mandatory lane changes is similar to that employed in INTRAS.

A vehicle undergoing a mandatory lane change will accept a less desirable gap size and gap location as the distance remaining over which a lane change is still possible, decreases. This increasing urgency to complete the manoeuvre is reflected in the increasingly high deceleration rate the driver is willing to apply. Thus, deceleration is a decreasing linear function of the proportion of total distance remaining over which a lane change can be made (Figure 5.3).

If, due to heavy congestion and lack of a suitable gap, the vehicle is unable to complete the manoeuvre, the vehicle will decelerate to rest and wait until such time as a suitable gap is available.

A forcing function is also employed such that when the vehicle attempting the manoeuvre and the vehicle following the gap in the adjacent lane is travelling at less than 0.91 m/s (3.3 km/h), the manoeuvre will be made regardless of the gap size. This reflects a jam situation where vehicles will physically force their way into the traffic stream.

At times however, especially with trucks, the *movie* will display these vehicles as overlapping. In effect they are, however, proper separation distances are achieved and maintained once the queue begins to dissipate.

Desired

Desired lane changes are similar to Mandatory manoeuvres except they are, as their name suggests, desired in anticipation of a future mandatory change. This concept

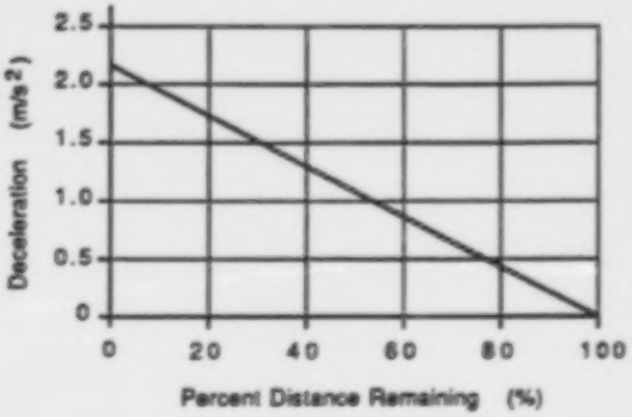


Figure 5.3: Acceptable deceleration as a function of remaining distance

is illustrated in Figure 5.4 in which a vehicle is travelling along a three lane freeway section, approaching an off ramp, on which it must exit.

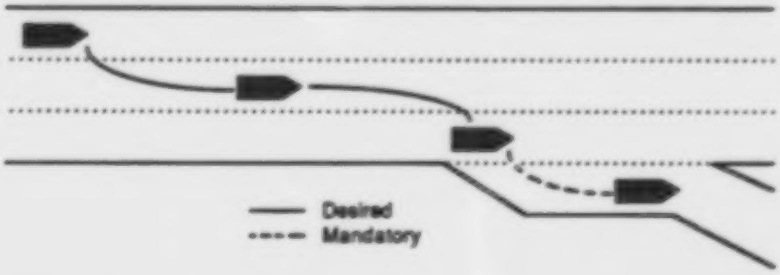


Figure 5.4: Desired lane change illustration

The driver of the vehicle in Figure 5.4 has been informed via an early warning sign, that his/her exit is the next exit on the right. In anticipation of the requirement of being in the correct lane to exit, the driver will desire to change into the shoulder lane in advance of the actual exit. However, the matter is not yet urgent and as such he/she will not accept undue risk in order to complete this desired manoeuvre.

A driver will *look* up to 457 metres (1500 ft) downstream of his/her current position to determine if a future mandatory lane change will be required.

5.4.2 Behavioural manoeuvres

It was observed from data gathered from the QEW between Highway 427 and 403, and general observance of freeway traffic that significant numbers of lane changes occur for reasons other than geometry based.

Based on the assumption, as discussed in Chapter 2, that many driver actions are governed by the driver's self-interest, it was hypothesized that there exist two types of behavioural lane changes;

- Passing to increase speed.
- Yielding to following traffic.

Passing

Passing is predominately governed by a driver's self interest — that of maintaining or increasing speed. The process of a driver deciding to make a passing manoeuvre can be divided into four phases: the driver becoming frustrated enough with his current state to desire to improve it, the driver deciding which lane provides the greatest improvement over the current state, the driver deciding whether the improvement will be significant enough to warrant the manoeuvre, and the actual attempt to engage in the manoeuvre. This sequence of events is depicted in Figure 5.5 along with the specific decisions and evaluations the driver must make in each phase.

To determine if a driver will attempt to pass, it must first be established that the driver is unhappy with the present state. A driver is assumed to be satisfied with the present state if the vehicle is currently undergoing a positive acceleration in excess of $0.3048\ m/s^2$ and as such will not consider a passing manoeuvre.

Dissatisfied drivers are those who are impeded by another vehicle. To assess if a driver is dissatisfied, the *desired* acceleration of the vehicle is determined. The desired acceleration is the acceleration determined from car following theory which will be applied if unrestricted by vehicle performance (i.e. a truck on a grade may wish to accelerate, but can not, due to restrictions imposed by critical power/weight ratio, or a vehicle might wish to accelerate at an extremely high rate, but is restricted by car performance). Characteristics of vehicles currently defined for FREEVU are presented in Appendix A.

If a vehicle's desired acceleration is negative, the implication is that the vehicle is decelerating to maintain a suitable gap between itself and the downstream vehicle. Drivers in this situation, slowing down due to other drivers, are considered dissatisfied.

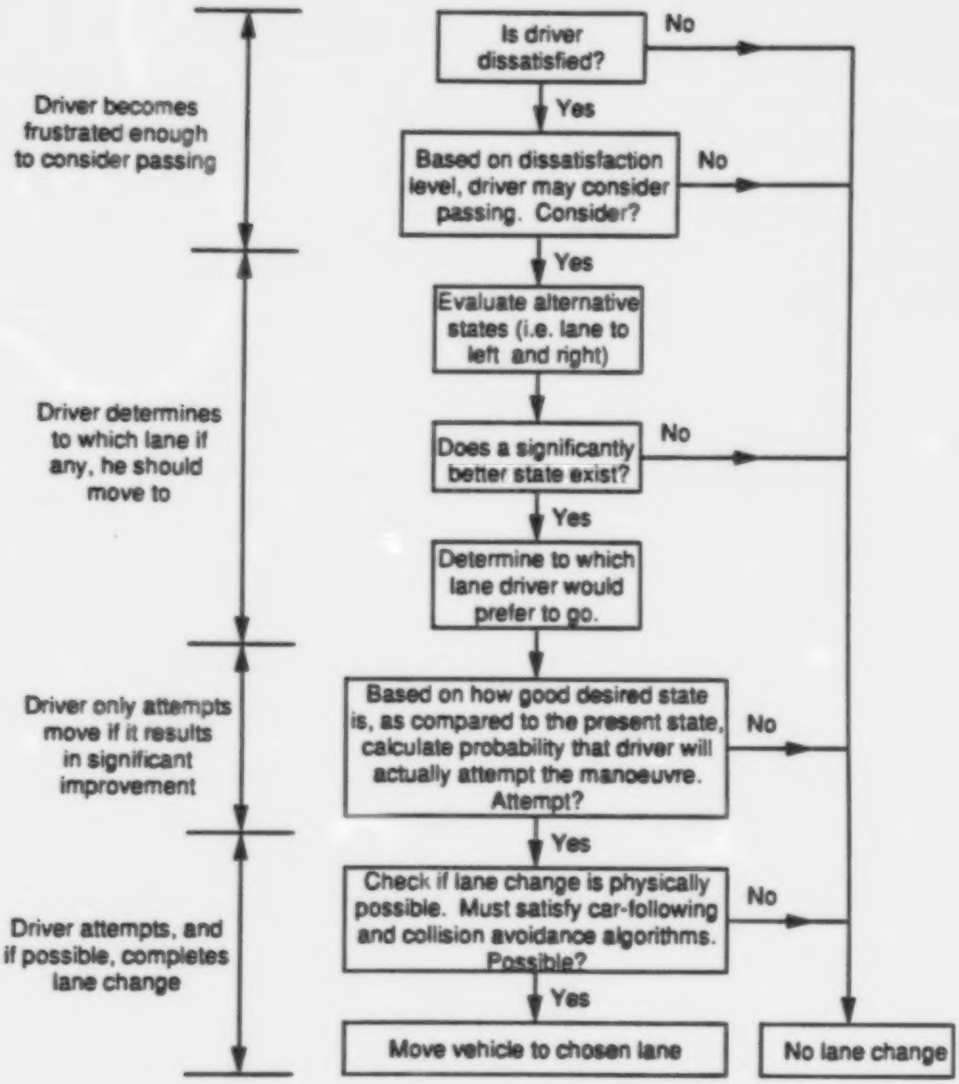

Driver becomes frustrated enough to consider passing
Driver determines to which lane if any, he should move to
Driver only attempts move if it results in significant improvement
Driver attempts, and if possible, completes lane change
Is driver dissatisfied?
No
Yes
Based on dissatisfaction level, driver may consider passing. Consider?
No
Yes
Evaluate alternative states (i.e. lane to left and right)
Does a significantly better state exist?
No
Yes
Determine to which lane driver would prefer to go.
Based on how good desired state is, as compared to the present state, calculate probability that driver will actually attempt the manoeuvre. Attempt?
No
Yes
Check if lane change is physically possible. Must satisfy car-following and collision avoidance algorithms. Possible?
No
Yes
Move vehicle to chosen lane
No lane change

Figure 5.5: Driver decision process for passing manoeuvre based on "self-interest"

As well, vehicles having a desired acceleration which is positive but not large (≤ 0.3048 m/s^2), and are travelling at a speed considerably less (≥ 3.05 m/s) than their desired free speed are also considered to be dissatisfied.

Since it is not realistic for every vehicle that is being forced to slow down to consider passing, some measure of the driver's dissatisfaction or frustration, caused by the slowdown is required.

It was assumed that 2 factors affect a driver's frustration; the vehicle's acceleration potential, and the difference between the driver's desired free speed and the vehicle's current speed. The *Frustration Index* (FI) reflecting the driver's dissatisfaction is the product of the two factors. (Note that acceleration has units of 10 × ft/sec^2 due to internal representation of digits of accuracy through the use of integer variables multiplied by the appropriate multiple of 10. The speed difference has units of ft/sec.)

As illustrated in Figure 5.6, the probability, during each scanning interval, that a driver will be frustrated enough to consider passing is directly proportional to FI, with a maximum of a 40% probability.

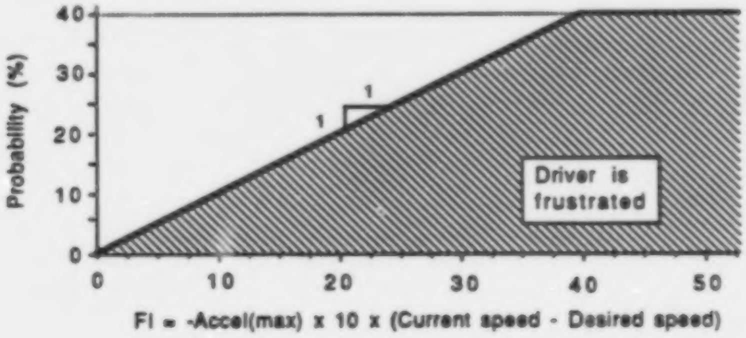


Figure 5.6: Frustration Index

If the driver is deemed frustrated enough to consider passing, a more favourable state must exist, else no lane change is warranted.

To determine if a more favourable state exists, the time required for the current vehicle to overtake the downstream vehicle is calculated. This time is a function of the speeds of the two vehicles, their respective positions, length, and accelerations. Since it is assumed that acceleration is constant over the time interval, simple equations of motion can be used to describe the vehicles' movements.

Consider the two vehicles in Figure 5.7. At some time interval, T, the position,

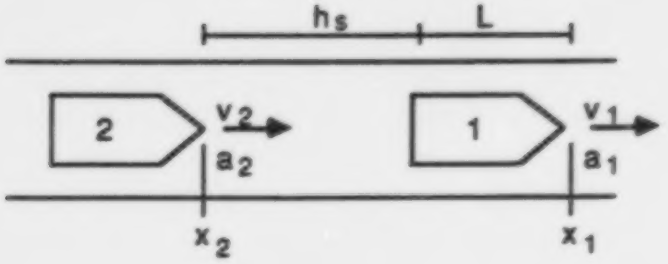


Figure 5.7: Time headway between two vehicles

x, speed, v, and acceleration, a, for each vehicle is known. From physical laws of motion, Equation 5.12 can be derived to describe the motion of each vehicle.

$$x = x_0 + vt + \frac{at^2}{2} \tag{5.12}$$

Each vehicle's motion can be described using Equation 5.12. The time t, is the time required for the following vehicle to overtake the leading vehicle such that both vehicles are at the same position, x. To solve for the time headway, the two expressions are equated and solved for t.

$$x_{0,1} + v_1t + \frac{a_1t^2}{2} = x_{0,2} + v_2t + \frac{a_2t^2}{2}$$

$$\frac{1}{2}(a_1 - a_2)t^2 + (v_1 - v_2)t + (x_{0,1} - x_{0,2}) = 0 \tag{5.13}$$

Solving Equation 5.13 using the quadratic formula,

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2}$$

$$t = \frac{(v_2 - v_1) + \sqrt{(v_1 - v_2)^2 - 2(a_1 - a_2)(x_{0,1} - x_{0,2})}}{2} \tag{5.14}$$

Since t must always be positive, only the positive root of the discriminant is considered in Equation 5.14. As well, if the discriminant is negative, no real root can be found, implying that the following vehicle never overtakes the leading vehicle. In this case the time is set to 500 seconds.

It should be noted that this method assumes that the vehicles continue at their present acceleration and velocity. This is often untrue as vehicles tend to change speed and acceleration frequently, however, drivers must base their decisions on information available to them in the present. They may have some ability to *read* downstream traffic, but they do not have foreknowledge of the leading vehicle's actions.

Having now established a means of quantifying *desirability* of a position, positions in adjacent lanes to the left and right are compared to the current state.

If the current state is found to be the most favourable (i.e. having the largest overtaking time), no lane change is made. Also, since there must be a significant advantage to making the lane change, a difference in overtaking time of an adjacent lane over the current lane of up to 13 seconds results in the current state being chosen. If however, there exists in either adjacent lane, an overtaking time greater than that of the current state plus 13 seconds, a lane change may be attempted.

It is assumed that there exists among drivers a tendency to prefer passing on the left, rather than on the right. In accordance, given that a favourable state exists in both the adjacent lane to the left and right, a driver will consider a change to the left unless the overtaking time in the right lane is 5 times as great as that of the left lane.

Having decided on which direction to consider for making a lane change, a probability that the driver will physically attempt the lane change exists. This probability is based on the amount of improvement over the current state the driver will receive. Figures 5.8 and 5.9 illustrate these probability functions for passing on the left and right respectively.

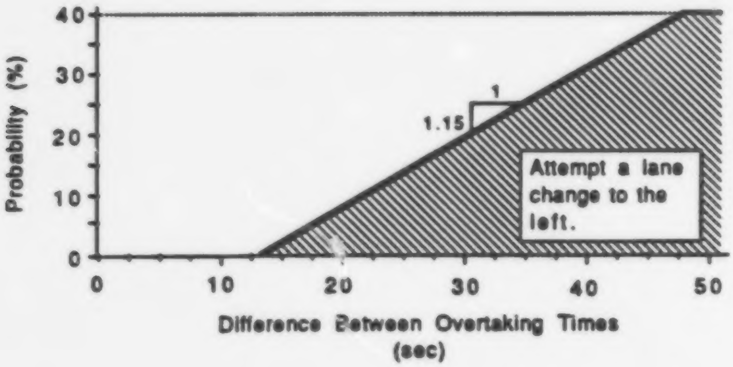


Figure 5.8: Probability function for passing on left

If a driver attempts the lane change, it must be physically possible for the vehicle to complete the lane change (i.e. a sufficient gap must exist) else no lane change is made. This criteria is checked in the same manner as for all lane changes.

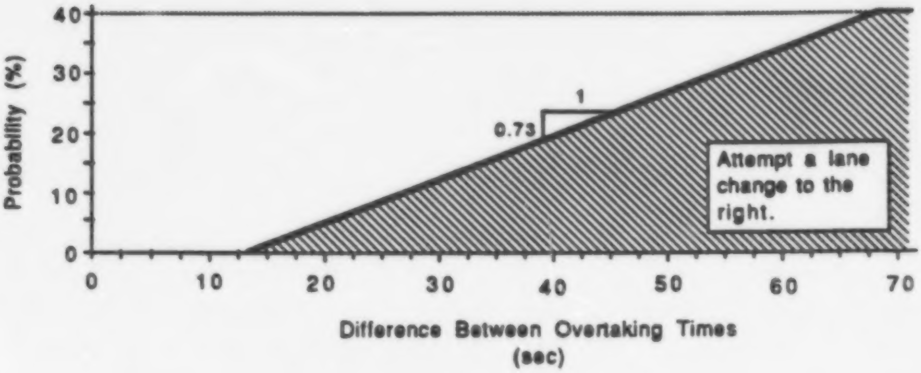


Figure 5.9: Probability function for passing on right

Yielding manoeuvres

Yielding manoeuvres, changing lanes to the right to benefit the following vehicle, are governed more by courteousness to other drivers than by self-interest. Yielding manoeuvres can occur in two situations; if a vehicle can not maintain its speed on a grade due to inadequate vehicle operating characteristics, or secondly, if the vehicle simply desires to travel more slowly than other vehicles. In either case, for a vehicle to engage in a yielding manoeuvre, it must be impeding the flow of the following vehicle.

For a vehicle unable to maintain its speed, the probability function for yielding is similar to the frustration index, in that it is composed of the product of the maximum attainable acceleration and the difference between desired free speed and the current speed (Figure 5.10). The probability of yielding is limited to a maximum of 80%.

For the second yielding situation, in which a vehicle desires to travel much slower than other vehicles, there is a 5% probability that it will yield during any simulation interval. The yielding manoeuvre will only take place if, as with the previous situation, the current vehicle is impeding the flow of the following vehicle, and in addition, the current vehicle will not be impeded by a downstream vehicle after the lane change is made. This reflects the fact that drivers, who are voluntarily travelling more slowly than the rest of the traffic stream, will not yield if doing so results in themselves being impeded.

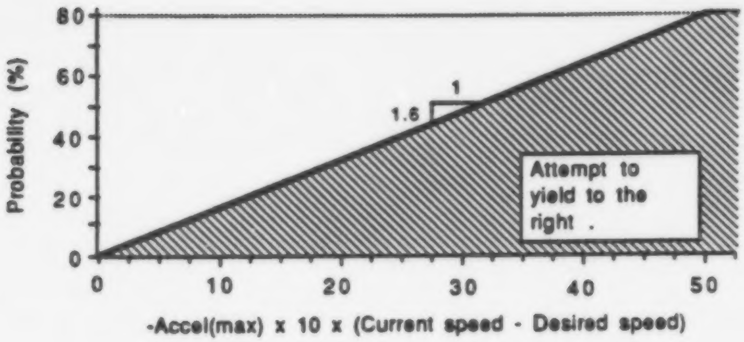


Figure 5.10: Probability function for yielding to the right

5.5 Maximum attainable acceleration

The maximum acceleration which the current vehicle can achieve depends on the vehicle's current velocity, the grade the vehicle is currently operating on, and the vehicle's power and weight characteristics.

The current grade is determined from the vehicle's position and lane. The grade has been specified previously by the user and is aggregated such that grades are defined for each 152 metre (500 ft.) segment of each lane. Currently only integer grades are permitted.

The maximum attainable acceleration is then determined from the vehicle's maximum tractive effort and current tractive resistance (Equation 5.15).

The tractive effort can be determined from Equation 5.16 and the tractive resistance is the sum of the grade, rolling and drag resistances (Equations 5.17, 5.19, 5.18, and 5.20) [46]. Notation is described in Table 5.3.

$$a = \frac{(T_E - T_R)}{G} \tag{5.15}$$

$$T_E = 2175\frac{P}{v} \tag{5.16}$$

$$T_R = R_r + R_g + R_d \tag{5.17}$$

$$R_r = (7.6 + 0.056v)G \tag{5.18}$$

$$R_g = 10Gm \tag{5.19}$$

Table 5.3: Table of notation

Symbol	Description	Units
a	maximum acceleration	m/s^2
A	frontal area	m^2
C_d	drag coefficient	trucks = 0.037 cars = 0.0011
G	vehicle weight	kN
m	grade	%
P	engine power	Hp
R_d	air drag resistance	N
R_g	grade resistance	N
R_r	rolling resistance	N
T_E	tractive effort	N
T_R	tractive resistance	N
v	velocity	km/h

$$R_d = C_d A v^2 \tag{5.20}$$

In FREEVU all internal computations are carried out using imperial units of measure. As such, the units used in the above formulae have been converted within the program code.

It should also be pointed out that the resulting acceleration, a, is the maximum possible acceleration rate, however, vehicles operating at highway speeds are assumed to accelerate at *comfortable* acceleration rates. As such, the acceleration rates calculated using Equations 5.15 to 5.20 are rarely observed. The purpose here is to identify the maximum acceleration rate which vehicles can attain as this value is used during the lane change decision process. For example, if a vehicle has a very low maximum acceleration rate, such as a loaded truck operating on a steep grade, it may yield to following traffic. Or, if a car has a very high maximum acceleration rate, the driver may decide to make a lane change to increase speed.

5.6 Detector loops

Detector loops modelled by FREEVU are used to record speed and volumes across all lanes. Detectors record information about vehicles and report averages at a constant

30 second interval. These measures can then be directly compared to actual loop detector data recorded in the field.

Average interval volumes are determined by simply recording the number of vehicles passing each detector loop during the recording interval. This value is adjusted (Equation 5.21) to reflect hourly volumes. The counter is reset and recording of passing vehicles is begun again for the next interval.

$$V = N(\frac{3600}{t_D}) \tag{5.21}$$

where V is volume in vph; N is the number of vehicles observed during time period t_D; and t_D is the observation period duration in seconds.

Average interval speeds reported by the detectors are space mean speeds, $\overline{u}_s$, where space mean speed is the harmonic mean of the observed spot speeds [45].

$$\overline{u}_s = \frac{N}{\sum_{i=1}^{N}(\frac{1}{u_i})} \tag{5.22}$$

where $\overline{u}_s$ is space mean speed in km/h; N is the number of vehicles observed; and u_i is the observed spot speed of vehicle i.

Densities are then derived from the general relationship,

$$V = Du_s$$

where D is the density expressed in v/km.

Chapter 6

Model validation and evaluation

6.1 Introduction

The ultimate purpose of using a simulation program, is to realistically and consistently reflect reality. To ensure the model is capable of fulfilling this purpose, its ability to simulate reality must be verified.

This validation can be conducted in at least three different levels of detail as represented in Figure 6.1:

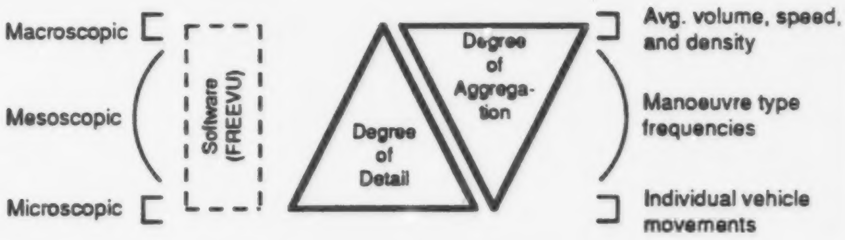

Macroscopic
Mesoscopic
Microscopic
Software (FREEVU)
Degree of Detail
Degree of Aggrega-tion
Avg. volume, speed, and density
Manoeuvre type frequencies
Individual vehicle movements

Figure 6.1: Various levels at which validation can be focussed

Microscopic dealing with each individual decision made in the simulation.

Macroscopic dealing with only the final, aggregated average measures such as speed and density.

Mesoscopic dealing with more detail than at the macroscopic level, and less detail than at the microscopic level — such as number of vehicle lane changes.

It is very difficult to validate at the microscopic level. Due to the amount of detail at this level, data requirements would be prohibitive, especially considering the natural variation and randomness in traffic.

At the macroscopic level, validation is more easily carried out. FREEVU has been developed to provide detector measures in the same traditional format as that of induction loop detectors most commonly used for in field data collection. Thus, program results are directly comparable to those obtained from monitored freeway sections. The disadvantage to validation at this level is that any discrepancies noted between the simulation results and the observed data, are not easily attributed to specific program algorithms, making it more difficult to determine what portion of the model is not adequately describing driver behaviour.

A compromise can be achieved by conducting validation at some intermediate level. Adequate detail exists to relate results to underlying driver behaviour algorithms, yet data can be obtained with sufficient detail and quantity to permit practical analysis.

Thus validation can be practically carried out at two levels within the simulation program — the macroscopic level and the intermediate, or mesoscopic level.

The chronological order of development and testing of FREEVU is illustrated in Figure 6.2. In addition to validations conducted during development of FREEVU, the parent programs, INTRAS and FOMIS, have been validated and evaluated by a number of different users [40, 52, 53, 13, 21, 54]. This can be referred to as the *first level* of validation of the model. Care has been taken not to change parameters unless there was considerable evidence to support new values.

Initial modifications were made to FOMIS to permit the modelling of trucks on grades. This enhanced FOMIS version was evaluated using data from the QEW on the Burlington Skyway. Observations and conclusions regarding the model's abilities and inadequacies led to a number of improvements. These can be considered to be *second level* enhancements. Included in these enhancements was the interface design shell. This new model, FREEVU, was evaluated and validated using data from the FHWA and the QEW in Mississauga. Conclusions and recommendations from this evaluation form the basis for recommended future *third level* enhancements.

It should be pointed out, that a case study had been proposed to the MTO in which FREEVU would be used to analyze a design problem which the Planning and Design Department had previously dealt with, or was currently working on. This would have allowed for valuable feedback from the designers, regarding the logic and structure of the user interface, and appropriateness of current output options. However, the MTO was not able to make such a commitment and the case study was not conducted.

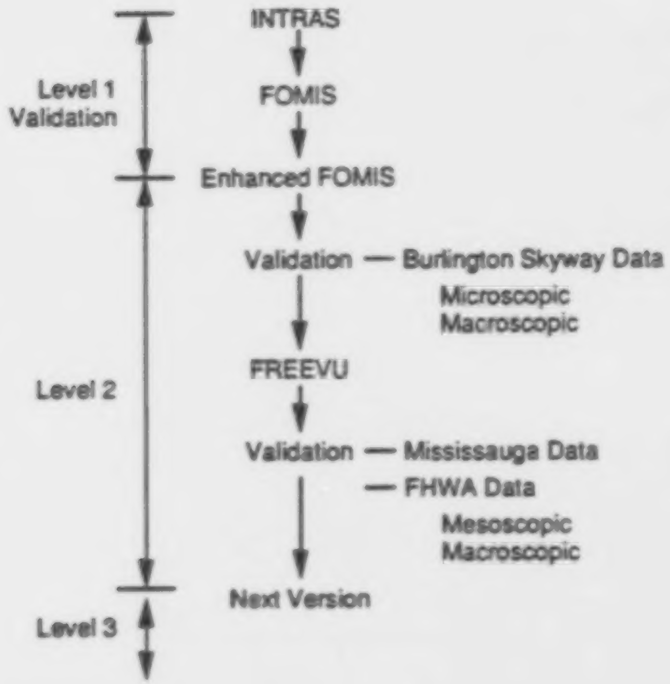

INTRAS
FOMIS
Level 1 Validation
Enhanced FOMIS
Validation — Burlington Skyway Data
Microscopic
Macroscopic
Level 2
FREEVU
Validation — Mississauga Data
— FHWA Data
Mesoscopic
Macroscopic
Next Version
Level 3

Figure 6.2: Chronological development and testing of FREEVU

6.2 Burlington Skyway validation

The Burlington Skyway validation of the enhanced FOMIS model had the following two objectives:

1. Investigate the behaviour of the model at the **microscopic** level. It was presumed that this analysis would be limited by available data.
2. Ensure realistic model behaviour at the **macroscopic** level. This involved comparing simulated and observed average speed and volumes for each lane at various locations. Also the distribution of vehicles, and specifically trucks, across lanes was examined.

Two data sources were used during this validation — one week of detector data and a manual traffic count conducted at the same location.

Burlington Skyway data

This data, obtained from the Ministry of Transportation of Ontario (MTO), was recorded by a series of detectors at six locations along the QEW between Highway 403 and the southern limit of the Burlington Skyway (Figure 6.3). The data consisted of detector output, produced at 30 second intervals, for the seven day period from April 19 to April 26, 1987. The output included flows in vehicles per hour, occupancy, and average speed over the 30 second period.

This section contains a number of 1 and 2% grades as well as the long 3% grade which occurs as the freeway approaches and traverses the Skyway itself (Figure 6.4).

Only the data from the five weekdays, from 6:00 a.m. to 8:59 p.m. was used as the manual counts providing the truck volumes applied only to weekday traffic. Also, it was felt that during night time hours, many intangible parameters existed which could affect driver behaviour (i.e. reduced visibility, different driver type, weather conditions, etc.). These intangibles could not be effectively modelled so the data reflecting night time conditions was not used.

Manual traffic count data

A manual traffic count was conducted by the MTO in order to determine the proportion of trucks in the traffic stream on an hourly basis. This count was carried out in December, 1986. Total hourly volumes from the manual count were compared to those

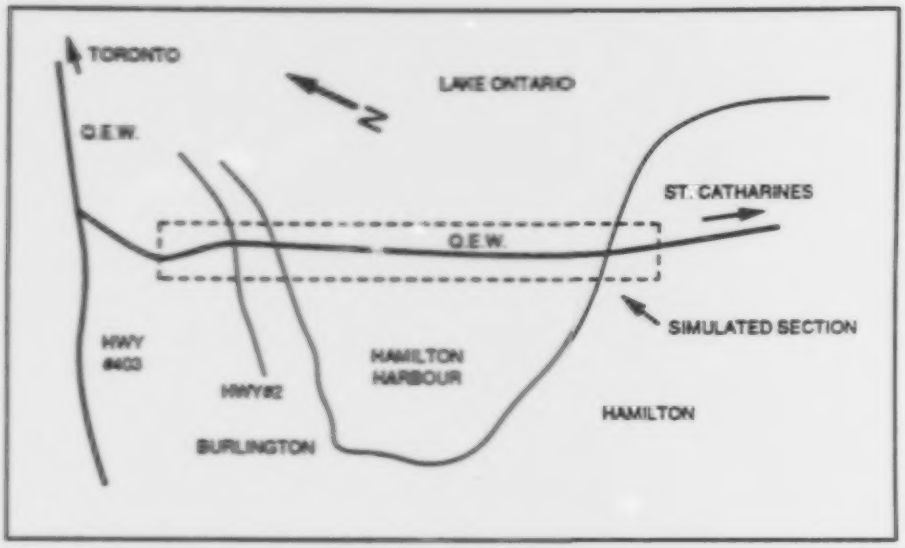

TORONTO
LAKE ONTARIO
N
Q.E.W.
ST. CATHARINES
Q.E.W.
SIMULATED SECTION
HWY
#403
HWY#2
HAMILTON
HARBOUR
HAMILTON
BURLINGTON

Figure 6.3: Location of monitored freeway section in Burlington

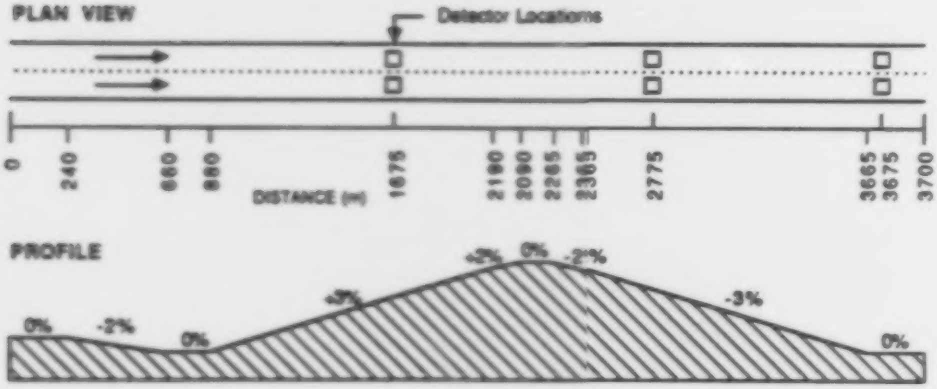

PLAN VIEW
Detector Locations
0
240
660
860
1675
2190
2090
2265
2365
2775
3665
3675
3700
DISTANCE (m)
PROFILE
0%
-2%
0%
+3%
+2%
0%
-2%
-3%
0%

Figure 6.4: Plan and profile of Burlington Skyway simulated section

of the detector data and found to be somewhat different. The greatest discrepancy occurred during the afternoon peak with an error of 36% of the loop detector volumes. This discrepancy may exist due to the different times at which the data was recorded. The manual counts were conducted in December, four months prior to the recording of the detector data in mid-April. The traffic composition, weather conditions, road conditions, and driver behaviour was likely different between these two times.

Despite these problems, since the manual count data was required to provide the proportion of trucks in the traffic stream, and no other data was available, the manual count data was used.

6.2.1 Validation

The Burlington Skyway validation of the enhanced FOMIS model consisted of two stages: microscopic and macroscopic. The validation process was constrained by the available data from the detectors and the rather suspect manual counts. In addition it quickly became clear that the Burlington Skyway is not a *typical* freeway section. Sections of the freeway have a posted 80 km/h speed limit (at the time of data collection). There is a good view from the top of the bridge, there are often strong winds present, etc. For these reasons the calibration of the enhanced FOMIS model was limited to achieving a reasonable fit to the observed data without extensively modifying the parameters in the model which have been calibrated previously during development of INTRAS.

Stage 1: Microscopic

Stage one concentrated on the microscopic calibration of non-essential lane changing and at a macroscopic level, achieving the proper distribution of vehicles across all lanes within the limits of the available data. Non-essential lane changes are those made based on drivers' self-interest rather than geometric or destination requirements. It was accepted at this stage that due to lack of data, this validation would be limited.

Two components of non-essential lane changing were examined for realism using subjective evaluation since no observed data was available:

1. Number of lane changes.
2. Realism and appropriateness of individual lane changes.

Stage one calibration was achieved by simulating a two lane section of the QEW which included the Burlington Skyway. This section was chosen because of the absence of ramp effects on lane changing manoeuvres.

The test section was simulated under various traffic volumes, with various proportions of trucks in each traffic stream. Lane change data was examined subjectively to ensure individual lane changes were realistic. Lane change frequency was also examined. Results were determined to be acceptable with respect to both quality and quantity of lane changes though the need for further validation with respect to lane change frequency was realized.

At the macroscopic level, lane distributions were found to be acceptable in the lower volume range, but at higher volumes the lane distributions were not comparable with real data. However, since the Skyway has inherent characteristics which are not possible to model with enhanced FOMIS (i.e. effect of wind, driver tendency to slow down due to height, tendency to 'sight see', etc.), and which might bias the data, preliminary validation results were considered acceptable.

Stage 2: Macroscopic

Stage 2 concentrated on the macroscopic validation of the model for a larger, more complex section including a weaving section, ramp effects and lane drops (Figure 6.5).

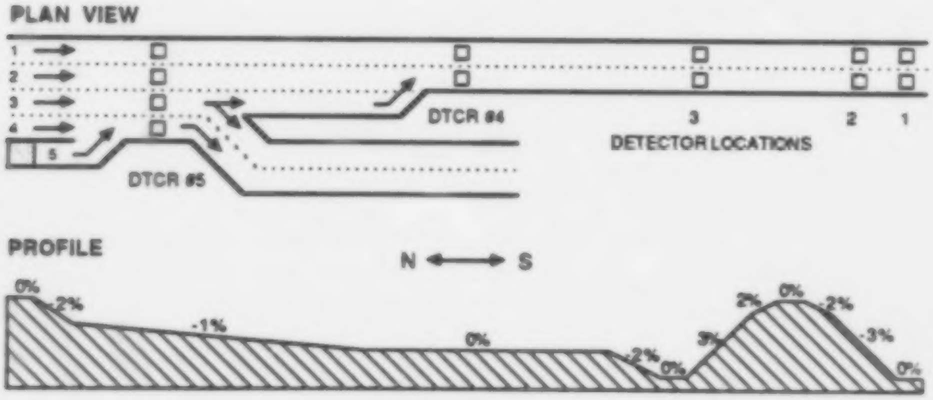


Figure 6.5: Extended section of QEW simulated

A 15 minute segment of data, describing traffic characteristics from 7:00 – 7:15 a.m., Monday, April 20, 1987, was selected from the MTO data set to be used for comparisons. This segment was examined to ensure that the data was representative of average conditions for the morning peak period.

Confirmation of correct lane volumes was accomplished first. The enhanced FOMIS model was used to generate volumes comparable to those observed at the upstream boundary of the section. Lane volumes produced by the simulation were compared to the observed data at the various downstream detector locations (detector numbers 1 through 5). Based on this comparison, the origin - destination matrix was adjusted until the correct proportion of vehicles were entering and exiting the section.

As illustrated in Figure 6.6, lane volumes were generally found to be similar between the enhanced FOMIS model and the observed data.

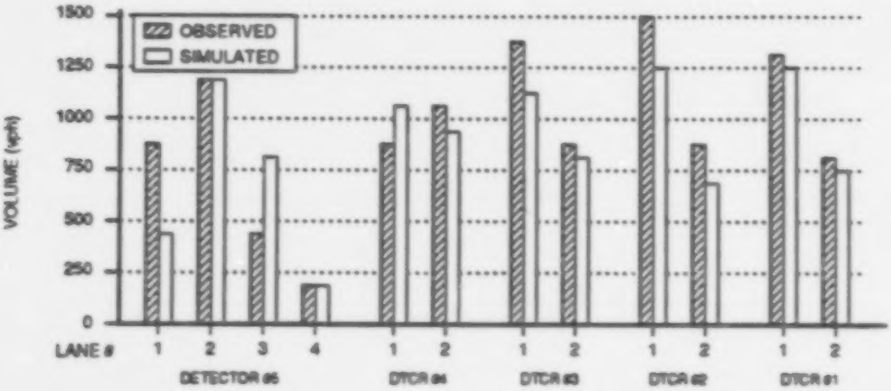


Figure 6.6: Morning peak — average volume comparison

Two observations were made:

1. A discrepancy occurred in the weaving section (detector location #5) where the model consistently over estimated the volume of traffic occurring in lane #3. Likely, in reality, drivers are aware of the downstream lane drop and in anticipation of this, tend to move into lane #2. The model however, does not have this ability to look ahead.
2. A further observation was made regarding vehicle generation. With the current vehicle generation method, it was difficult to consistently produce desired volumes. It was concluded that the generation algorithm should be improved.

Simulated and observed speeds, averaged over 15 minutes, were compared for each detector (Figure 6.7).

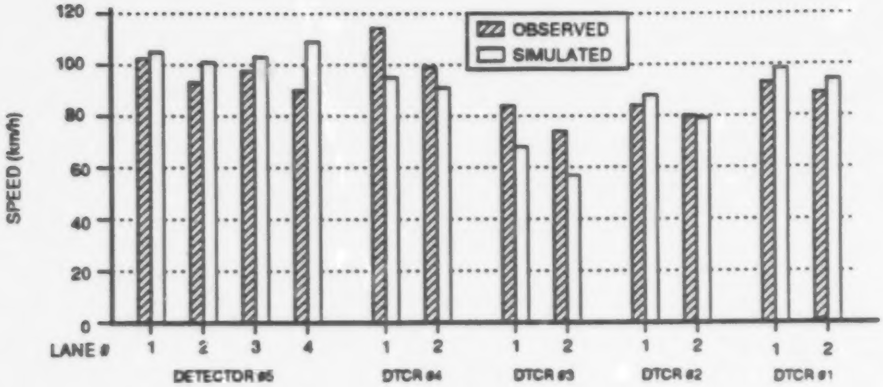


Figure 6.7: Morning peak — average speed comparison

The enhanced FOMIS model produced average speeds which had a similar pattern to the observed data, however, the existing discrepancies led to four conclusions:

1. The speed profiles produced by the enhanced FOMIS model seem to indicate that the vehicle speed distribution used may be too high. This is indicated by the average lane speeds being higher than observed for both detector locations 1 and 5. For the other locations, vehicle interactions in the weaving section, and the grade effect on the Skyway have caused a lower average lane speed.
2. Speed reductions on the grade seem excessive. The vehicle stream composition, particularly truck types and vehicle characteristics, should be verified.
3. Examination of detector locations 1, 2, and 3, indicates that observed behaviour was not simulated accurately. Upon further investigation it was discovered that the posted speed limit in this region was only 80 km/h. The enhanced FOMIS model was unable to model this transition zone in which the vehicle speeds are often governed by the reduced speed limit.
4. The need for visual representation of the traffic flow would be invaluable for understanding the microscopic traffic dynamics which can not be captured by aggregated measures of effectiveness.

Following this initial validation, a number of improvements and enhancements were made to the model, some of the more important being listed below.

- Implementation of a user interface for data input and analysis of results.
- Creation of ability to view vehicles as they travel along section.
- Improved vehicle generation.
- Modification and verification of data file of vehicle characteristics.
- Implementation of speed limits and capability to model speed transition zones.
- Capability to incorporate truck restriction in passing lane.
- Comprehensive lane changing algorithms developed.

6.3 Mississauga validation

The second validation exercise was undertaken once all modifications and enhancements to the enhanced FOMIS model were completed. This new model was renamed FREEVU. The purpose of this second validation was to:

1. Calibrate and validate at a mesoscopic level the alterations made to the model — particularly the lane changing algorithms.
2. Reinforce the previous validation's conclusions that the model realistically simulates freeway traffic at the macroscopic level.
3. Ensure that a variety of data was used for validation to avoid any site specific inherent characteristics which would unduly bias the validation.

Data from the QEW eastbound between Highways 403 and 427 was obtained from the MTO. To allow for visual validation of this detector data and provide lane change frequency data, a section of the QEW eastbound, corresponding to one of the loop detector stations, was video taped during the morning peak period.

Additionally, a data base of freeway traffic flow, created by the FHWA [55] was obtained to allow for further calibration and validation of the lane changing algorithms.

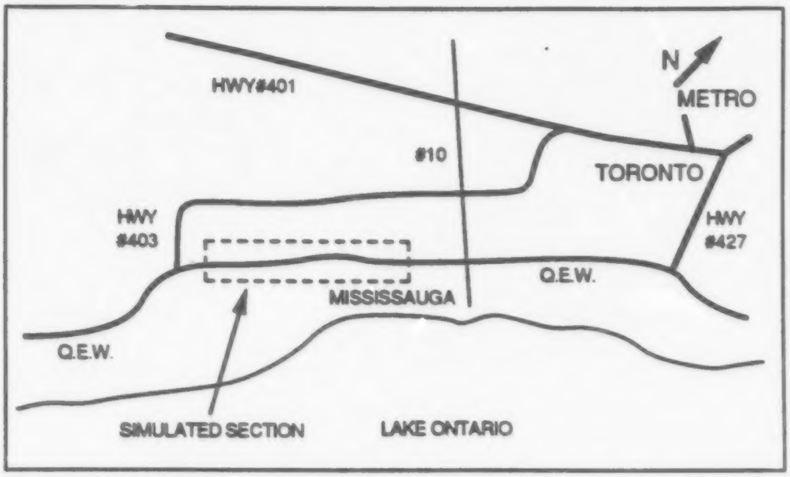


Figure 6.8: Location of Mississauga QEW section

6.3.1 QEW — Mississauga data set

The loop detector data obtained from the MTO described traffic conditions on the QEW eastbound between Highways 427 and 403, for the week beginning November 18, 1989 (Figure 6.8).

Along this section of the QEW are located 27 detector stations. These detectors were placed by the MTO in order to more effectively monitor and control commuter traffic heading into the city. A number of ramp metering stations are in operation here, as well as 2 overhead changeable message signs, and 18 surveillance cameras.

The detector data recorded consisted of flow (vph), occupancy (%), and speed (km/h) produced at 30 second intervals for each lane. As was done with the Burlington Skyway data, only data from the five weekdays was considered. In order to correspond to the video tape data, only detector data from 7:55 a.m. to 11:35 a.m. was analyzed.

A section of the monitored site, 6 kilometres long — from east of the QEW - Hwy 403 interchange to west of Mississauga Road, was simulated (Figure 6.9). Unfortunately, of the 30 loop detectors located within the site, only 15 volume loops and 4 speed pairs were operational.

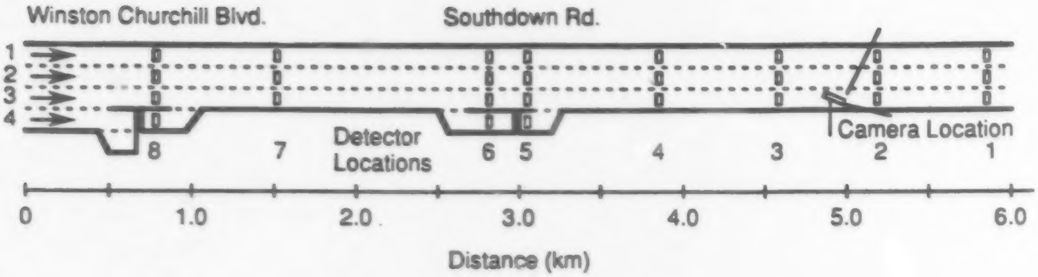


Figure 6.9: Simulated portion of QEW in Mississauga

6.3.2 Video tape data

The video tape was obtained directly from one of the 18 surveillance cameras situated along the QEW. This camera (TV station #04) is situated approximately two kilometres east of Southdown Road on the south side of the freeway (Figure 6.9). The camera head was positioned such that a clear view of all three eastbound lanes was obtained.

The video records traffic movements from 7:55 a.m. to 11:45 a.m. on Thursday November 23, 1989. This tape was analyzed to obtain car and truck counts per lane in 5 minute intervals for a total of 1 hour commencing at 7:55 a.m. This provided for a direct validation of the loop detector data.

Additionally, truck volumes and lane change manoeuvres were recorded per lane over 5 minute intervals for the entire 230 minutes of video. The truck volumes were necessary for subsequent simulation input. The lane change data was required to validate the lane changing algorithms previously hypothesized and implemented in the model.

Lane change data

Lane changes were recorded from the video tape by origin and destination lane. Lane changes were observed within a bounded portion of the video image. The length of this segment was determined to be 20 car lengths at jam density, or 200 metres. This segment is isolated from ramp effects, being approximately 2 km from both the nearest upstream and downstream ramps. The section has no appreciable grade or horizontal curvature.

Based on the number of vehicles observed during the time period, as obtained from the loop detector data, and a section length over which the observations took place, the number of lane changes per vehicle per kilometre was determined. Rates based on 15 minute observation intervals, were plotted against the average lane volume and a linear, least squares regression line fitted (Figure 6.10). (The data used to construct Figure 6.10 can be found in Appendix A.1). As can be seen, the range of observed average lane volumes is limited to between approximately 1000 and 1500 vphpl. However, within this range, the relationship between lane change rate and average lane volume is quite strong, with 77% of the observed variance explained by the regression equation. According to the Student t distribution, the hypothesis that the slope of the regression line is equal to zero can be rejected at a 99% level of confidence.

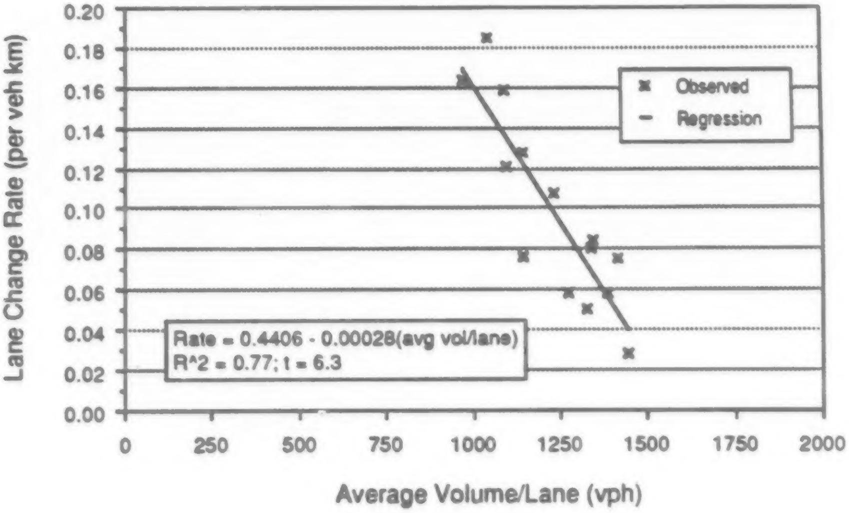


Figure 6.10: Non-mandatory lane change rates verses average lane volume

These results are interesting as they indicate a rapid decline in the lane change rate with increasing volume. Intuitively this is plausible — as volume increases to the point where few large gaps are present in the traffic stream, drivers receive little, or no benefit by changing lanes, so fewer changes are made. As well, as volume increases, the number of manoeuvres occurring is divided by an increasingly larger number of vehicles.

Loop detector validation

One hour of video tape was observed to determine total lane volumes. This data was compared to the compatible loop detector data (Table 6.1). For the total three lane volume, the maximum discrepancy was limited to 8.8%. Typically, loop detectors are designed to attain an error level of approximately 5% [56]. It was concluded that the detector data was accurate and within acceptable standards.

Table 6.1: Comparison of loop detector and video volumes for eastbound QEW

Time (a.m.)	Total Volume (vph)		Error (%)
	Video Tape	Detector	
7:55	3,776	3,988	5.6
8:10	3,896	4,040	3.7
8:25	3,980	4,332	8.8
8:40	4,204	3,980	-0.9

6.3.3 FHWA data set

The FHWA data set [55] consists of digitized aerial photography, taken at different sites across the U.S. Each site had been filmed for approximately 1 hour. From the film, complete vehicle trajectories were produced, recording the vehicle's position for each time interval. Data from five sites, describing different geometric configurations was selected (Table 6.2). A plan view and geometric details of each site appears in Appendix A.1.

Lane change data

Non-mandatory lane change rates were determined from the data for each of the five sections. Mandatory lane changes are those which have a ramp lane as either the origin or destination lane during a lane change. Rates were calculated as the number of lane changes observed, divided by the length of the section over which observation took place and the total number of vehicles observed over this section (Table 6.3). Due to computer tape difficulties, only two minutes of data were available for site 1. Lane change rates were calculated for completeness only, and no further analysis of this site was done.

Table 6.2: FHWA sections used for validation

Site Number	Location	Section Type
1	I–295 S.B. (Anacostia Freeway) between 11th Street and Howard Road, Washington, D.C.	weaving
2	I–95 S.B. at Backlick Road (Route 617) in Fairfax County, Virginia	on-ramp
3	I–395 S.B. (Shirely Highway) at Duke Street (Route 236) in Alexandria, Virginia	off-ramp
4	I–405 N.B. at Mulholland Drive, Los Angeles, California	tangent
5	I–405 S.B. at Santa Monica Blvd., Los Angeles, California	on-ramp

Table 6.3: Observed non-mandatory lane change rates per vehicle kilometre

Site	Lane Change Type		
#	Left	Right	Total
1	0.654	0.327	0.981 [a]
2	0.217	0.135	0.352
3	0.082	0.140	0.222
4	0.186	0.234	0.420
5	0.386	0.098	0.484

[a] Based on only 2 minutes of data

6.3.4 Validation

Mesoscopic

The mesoscopic validation primarily focussed on the lane change frequency rate. Data had been assembled from five separate sites; four from the FHWA data, plus the QEW section in Mississauga. Each site was simulated at the observed volumes, except where noted, using FREEVU. Simulation results are presented in Appendix A.1. Lane change data was recorded. Lane change rates for non-mandatory lane changes were calculated and compared to those observed (Table 6.4).

Table 6.4: Comparison of simulated and observed non-mandatory lane change rates per vehicle kilometre

Site	Observed			Simulated			Error
#	Left	Right	Total	Left	Right	Total	(%)
2	0.217	0.135	0.352	0.285	0.091	0.376	6.8 [a]
3	0.082	0.140	0.222	0.195	0.254	0.449	102.3 [b]
4	0.186	0.234	0.420	0.307	0.173	0.480	14.3
5	0.386	0.098	0.484	0.416	0.094	0.510	5.4 [c]
QEW	0.091	0.048	0.139	0.015	0.062	0.077	-44.6

[a] simulated volumes approximately 10% low

[b] simulated volumes approx. 17% low

[c] simulated volumes 13% low with breakdown occurring

Total simulation lane change rates compared well with those observed, with the discrepancies within 15%, except for the QEW section and FHWA site #3. FHWA site #3 had a major interchange located approximately 300 metres downstream of the site. This interchange affected lane changing manoeuvres, but it was not known in what way. As such, it was difficult to determine the non-mandatory lane change rate with accuracy.

For the QEW section, the distance over which lane changes were recorded was estimated to be 200 metres, based on an observed queue of 20 cars at jam density. It is possible that this distance was underestimated and that the distance per vehicle was in the range of 15 – 17 metres. This would translate to a total observed rate of 0.082 non-mandatory lane changes per vehicle kilometre. The simulated rate of 0.077 would only be in error by -6.1%. Given the presence of these uncertainties in the data from these two sites, it could not be concluded that the model does not reflect reality well, in terms of non-mandatory lane change rates.

The lane changing algorithms implemented in the model had been hypothesized. The required parameters had been selected intuitively and subjectively prior to any validation. Based on the results given in Table 6.4 the hypothesis regarding drivers' lane changing decision process is reasonable, and the parameters chosen, appropriate.

Macroscopic

The six kilometre section of the QEW presented earlier in Figure 6.9 was simulated for 5 minutes. The origin-destination matrix was altered to reflect the observed volume leaving the section at each exit. Comparisons with observed data, particularly for average lane speed, were limited due to the high number of inoperable loop detectors. Only two detector locations provided average lane speeds, and then only for the inside and outside lanes. Five detector locations provided volume counts.

The first comparison was made between the total three lane volumes observed and simulated. From Table 6.5 it can be noted that total three lane volumes are similar with the discrepancies ranging from -4.0% to 5.9% of the observed volume.

Table 6.5: Comparison of simulated and observed total three lane volumes for eastbound QEW

Detector Location	Total Volume (vph)		Error (%)
	Observed	Simulated[1]	
1	4,200	4,092	-2.7
2	4,332	4,224	-2.5
4	4,094	4,176	2.0
5	3,115	3,300	5.9
7	3,400	3,264	-4.0

[1] Simulated for 5 minutes

However, the distribution of these volumes across the three lanes, as shown in Figure 6.11, indicates that the simulation distribution is almost directly opposite that observed. The simulation results consistently show higher volumes in the shoulder lane and lower volumes in the passing lane than observed. This tendency is particularly evident downstream of the high volume ramp merge area at Southdown Road (detector location 5). It seems likely that in reality, drivers tend to avoid the shoulder lane in the ramp merge area, as they are able to anticipate the presence of the merging vehicles. FREEVU does not have this capability, resulting in very high shoulder lane volumes in the immediate vicinity, and downstream of, the high volume on ramp at Southdown Road.

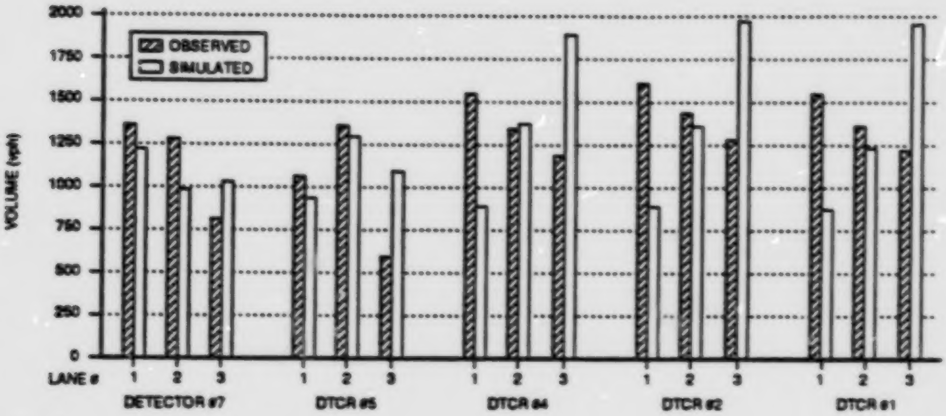


Figure 6.11: Comparison of simulated and observed average lane volumes for QEW section in Mississauga

A comparison of simulated and observed average lane speeds is illustrated in Figure 6.12. Note that no observed speeds were available for the centre lane.

From Figure 6.12 it is evident that simulated speeds are consistently higher than those observed; ranging from 20 to 37% higher than observed. Reexamination of the video tape data indicated that downstream of the study site, possibly at Mississauga Road, heavy demand was causing speed reductions within the study section.

A concern was also raised about the accuracy of the paired loop detector recorded speeds. Two of the detector locations provided speed data but not volume data due to an indicated loop failure. This seems unlikely to be true as both loops in the pair must be operational in order for speeds to be measured. Verification of the data aggregation procedure was not possible as the VAX computer which had been used to assemble the data from the MTO data tapes, had subsequently been permanently removed from operations.

From these observations, taking into consideration uncertainties with the data, it can be concluded that at the macroscopic level, FREEVU reflects reality reasonably, provided that the observed situation can be specified adequately.

To more fully evaluate FREEVU, a macroscopic analysis of the FHWA data sets was conducted. Similar traffic characteristics and flow patterns between the simulation and reality were necessary. At the macroscopic level, simulation results were

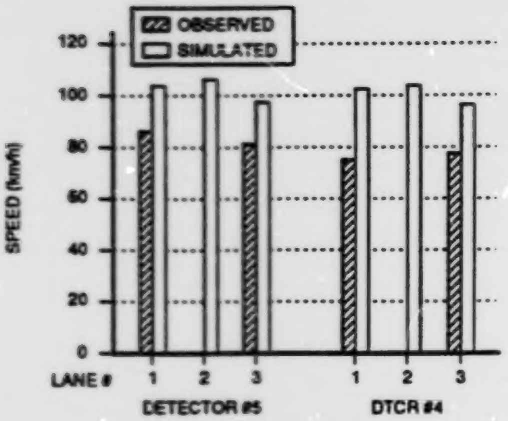


Figure 6.12: Comparison of simulated and observed average lane speeds for QEW section in Mississauga

compared to the observed data. It was found that in most cases, FREEVU performed adequately, being able to reasonably reflect reality, however in some instances significant discrepancies occurred. A detailed analysis of the sites, observed data and simulation results is provided in Appendix A.1. A summary of these comparisons is presented in Table 6.6.

Based on the detailed analysis presented in Appendix A.1, a number of specific observations and conclusions were made:

- In reality drivers are able to anticipate downstream conditions and adjust their behaviour accordingly.
- The minimum headway commuter drivers accept, seems to be consistently short and have little variance. This promotes better flow as breakdown tends to occur due to random extreme events.
- Visibility of downstream conditions seemed to affect drivers ability to anticipate downstream conditions. When traversing a downgrade, drivers vision of the downstream traffic flow is enhanced, allowing for shorter headways.
- Uncertainty about the types, loading, and proportions of trucks for all of the FHWA data may explain part of the differences noted between observed data and simulation results. This would effect FHWA sites 3 and 4 in particular as they contain steep grades.

Table 6.6: Qualitative summary of detailed validation results

Evaluation Feature	Validation Site					
	QEW		FHWA			
	Man.[a]	6 km.	2	3	4	5
Total flow	G	G	G	P	G	G/F
Lane distribution	F	P	F/P	F	F	F
Average lane speed	n.a.	P	F/P	G/F	F/P	G/F
Lane change freq's.	P	n.a.	G	P	G	G
Merging behaviour	n.a.	F	F	n.a.	n.a.	F
Breakdown process	n.a.	G	G	n.a.	n.a.	G

G = Good; F = Fair; P = Poor [a] QEW section for recording manoeuvre rates.

- FHWA sites are *worst case* scenarios, specifically chosen for their high congestion and restrictive geometry.

- FREEVU models the slowdown, queue build up and dissipation sequence well, except that it occurs at lower volumes than observed.

- FREEVU models non-mandatory lane change frequencies well.

- Momentum effects are not modelled by FREEVU. The significance of the impact of momentum is not known, though it is suspected that for short sections, having a significant upgrade and located downstream and in close proximity to a significant downgrade, this effect can be substantial, particularly for heavy trucks.

- FREEVU limits vehicle acceleration to *normal* rates. Grades may impact what drivers consider to be *normal*; accepting a higher acceleration on down grades, and lower rates on up grades.

- In FREEVU, for an off ramp situation under heavy flow, occasionally vehicles are *caught* in the median lane and can not access the off ramp. Since these vehicles wish to exit but can not do so, they decelerate so as not to miss their exit. As a result, vehicles will occasionally decelerate at emergency rates and cut across to the ramp lane, disrupting mainline traffic flow. This behaviour can also be observed, however, perhaps at a lesser frequency than is modelled.

- Ramp merging under heavy demand situations is not handled well by FREEVU. In the simulation, merging vehicles do not match their speeds to that of the mainline vehicles and as such require a large gap, reducing the maximum flow rate.
- Subjective visual observation of the FHWA data indicated that mainline vehicles seem to accept, at least temporarily, short, *unsafe* headways when ramp vehicles merged in front of them. These short headways produced higher flows than possible with FREEVU as it maintains safe headways.

In conclusion, it should be noted that variations within both the observed data, and the simulation results have not been rigorously investigated. It has been previously illustrated that large variation can be observed within typical traffic streams. FREEVU, being stochastic, also reflects this variation. Figure 6.13 illustrates the variation in simulation results for a short freeway section, with each 15 minute simulation run having the same volumes specified.

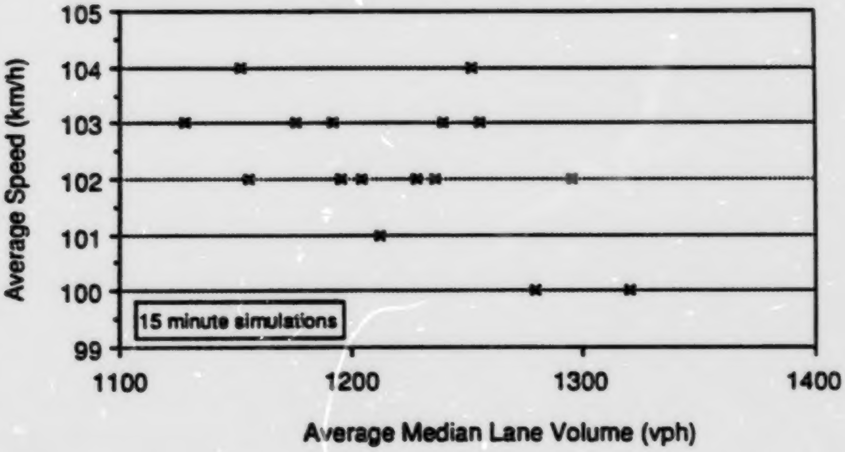


Figure 6.13: Variation in simulation results with constant inputs

6.4 Summary

FREEVU, though not yet perfect, seems to represent the mechanics of traffic flow reasonably well. The process of the development of break down appears realistic, although it occurs at lower volumes than observed. Lane change frequencies appear realistic. In addition, the ability of FREEVU to provide a view of the dynamic behaviour of the traffic flow greatly improves understanding of traffic flow and the traditional measures of effectiveness.

Based on the observations made and conclusions drawn, a number of potential, third level enhancements can be identified;

- Enhance merging behaviour at high volumes.
- Improve modelling of vehicles accessing off ramps.
- Incorporate concepts of anticipation and driver's ability to look ahead.
- Investigate how and/or if, the distribution of driver sensitivity changes over time and space.
- Determine if effects of momentum should be modelled.
- Determine grade effects on *normal* acceleration and deceleration rates.

The validation exercises undertaken in this work have been primarily based on "non-average" traffic conditions. All of the FHWA sites were specifically chosen, for the FHWA study, for their high levels of congestion and poor operating conditions. Thus, the evaluation of FREEVU was based on rather demanding data, beyond the scope of existing "average" methods of analysis.

Chapter 7

Conclusions and recommendations

7.1 Summary

This work was initially prompted by the growing need to deal with congestion, particularly on urban freeways. A number of typical potential strategies for reducing congestion were identified. However, it was recognized that these strategies must be evaluated in some way, within the transportation planning process. Traditionally, the Highway Capacity Manual has been the analysis tool of choice, however, it was hypothesized that a computer simulation design tool could prove to be a more flexible method, especially for "non-average" conditions.

Currently existing simulation models were identified. It was concluded that the INTRAS model family best suited the needs of a design tool. The model FOMIS, a restructured personal computer version of INTRAS, was obtained and evaluated, but found to be lacking in three areas; ease of use, simple to understand, and complete and accurate on important items. It was concluded that the model could be used to form the simulation core of an evaluation and analysis tool.

The freeway system was investigated. Traffic flow theory and the freeway components were examined in order to determine those that the simulation model needed to incorporate.

It was observed that significant variation exists in traffic flow behaviour and as a result, it was concluded that no one single measure of performance clearly and accurately quantifies the quality of traffic flow.

Examination of traffic stream behaviour revealed that truck effects on flow are significant, and can not be accurately reflected through some *typical* truck. It was concluded that the model should explicitly reflect different truck types and their reduced performance, particularly on grades.

Based on operating characteristics, four general vehicle classes were created. It was concluded that only cars and trucks need be explicitly modelled, though it remains possible for the user to define both buses and recreation vehicles in the vehicle data file. Six car and three truck categories were created to represent the observed vehicle type population. Vehicle performance capabilities were expressed using tractive effort and tractive resistance equations. It was concluded that lateral acceleration need not be modelled explicitly.

Driver characteristics were investigated. Two categories of human characteristics affecting traffic flow were identified; human physical limitations, and human self-interest. Physical limitations governed reaction times with many factors, including age, sex, fatigue, and driving experience, affecting these reaction times.

Drivers' self-interest was found to govern much of driver behaviour. Self-interest considerations define the maximum speed a driver is willing to travel at. As well, self-interest often determines driver lane changing behaviour. A comprehensive lane changing algorithm was hypothesized to describe drivers making lane changes in order to increase speed, or to yield to following traffic. This algorithm was incorporated into the model and subsequently tested.

Freeway system geometry was examined. It was decided that the model should have the ability to model the following components:

- unidirectional, multilane freeway segments of 2 to 8 lanes in width.
- lane adds and drops.
- on ramps — single lane from either the right or left side of the freeway.
- off ramps — single and multiple lanes from either the left or right side of the freeway.
- posted speed limit.
- vertical alignment with the ability to uniquely specify grades for individual lanes.

The planning and design process was investigated. The role of the model within this structure was defined. It was concluded that the simulation model would be most effective if implemented to evaluate alternative plans. The process for model use was determined such that the designer developed an alternative plan, traffic characteristics, and typical traffic volumes, and then used the model to simulate this scenario. Results would be examined and, if required, some other alternative plan examined.

The model, FREEVU, was created as a user-friendly design and analysis tool. The model is a stochastic, microscopic freeway traffic simulation program. A modified and enhanced form of FOMIS forms the simulation core. A design shell, created to surround the simulation core, enables quick, efficient, interactive data input and analysis of output.

A key feature of FREEVU is the ability to view a "movie" of the simulation results. This feature shows, the freeway section, or just some portion of it, as it would appear to an observer directly overhead in a helicopter.

Freeway sections can be simulated by adjustments to the model parameters and thus non-average situations can be modelled.

The presence of significant variation in traffic behaviour is reflected by the model. The ability to control the degree of aggregation of the results allows the user to investigate this variation.

The essential simulation capabilities of FREEVU have undergone a number of validations, first by various users of INTRAS and FOMIS. The enhanced FOMIS model was evaluated as was the final FREEVU model. Recommendations regarding potential future third level enhancements were made.

7.2 Conclusions

FREEVU, though not yet perfect, is a useful interactive, user-friendly, computer evaluation and design tool for the analysis of multilane freeway sections, and has many advantages over other existing methods.

In general, FREEVU simulated most traffic situations reasonably well.

The design shell proved to be invaluable, both for simplifying data input, and for ensuring that the section was properly defined. The ability to view a plan and profile of the defined section provided immediately visual feedback to the user regarding the section data input.

The *movie* feature greatly enhances the user's understanding of traffic flow over the simulated section. Traffic flow patterns, queuing, platoons forming behind slow trucks, and other flow phenomena are immediately visible to the user.

The "movie" feature also improves debugging, and will be useful as enhanced versions of FREEVU are developed.

FREEVU's simulation abilities are an improvement over the FOMIS model, but the greatest improvement is FREEVU's design shell. This shell eliminates the traditional need for tedious input by persons with expertise in the model structure and input formats. Often errors in input were not discovered until after many simulation runs, and output analysis. With FREEVU, input is simple, quick and follows a menu format which is familiar to most people.

Evaluations at the mesoscopic level, of FREEVU's simulation capabilities, indicate that non-mandatory lane change frequencies agree closely to those observed. Thus it was concluded that the hypothesized lane changing algorithm could be accepted as realistically reflecting drivers' decision process.

Incorporating extensive lane changing decision algorithms based on drivers' self-interest, in a simulation program is a unique innovation.

FREEVU simulated many traffic situations well, however, it has difficulties realistically simulating the actions of merging and to some extent, diverging vehicles under some moderate to high volume conditions.

The implementation of a driver's desired free speed based on the posted speed limit was useful. This permitted the control of overall speeds, particularly for ramp sections.

The ability to model a distribution of truck types was useful. The current vehicle data file contains 3 truck types (straight truck, tractor trailer combination, and tractor double trailer combination) with 3 different loadings for each type; empty, 50% loaded, and fully loaded. It is suspected that for some of the simulation runs, this data file contained more heavy trucks than the observed data.

Driver behaviour varies significantly between commuter and non-commuter traffic streams. Commuter streams seem to be more aggressive and homogeneous in nature than non-commuter streams. At times drivers appear to be rather insensitive to short separation distances, and accept, at least temporarily, unsafe following distances. FREEVU, based on collision avoidance algorithms, does not permit vehicles to follow at unsafe distances, except while in the process of making a lane change. Due to this, FREEVU is unable to achieve very high flow rates (i.e. in excess of 2000 vphpl), as was observed in some instances.

Drivers have the ability to anticipate downstream traffic conditions and respond to observed downstream events. FREEVU determines each vehicle's actions based on the next downstream vehicle in the current lane. This results in a traffic stream behaving in a more *reactive* nature than anticipatory. This lack of anticipation in the model also explains the discrepancies in volume distributions across lanes in the vicinity of ramp areas.

The aspects of FREEVU which seem to inadequately reflect reality, such as merging and diverging behaviours, drivers' anticipation of downstream events, and vehicle's travelling at unsafe following distances — all require rather extensive, accurate microscopic data bases in order to fully understand each event. The FHWA data used in this study would partially fulfill this need, however, this data only reflects areas of high congestion due to restrictive geometry. Some other sources would be required to investigate these phenomena in detail, in order to observe them under a wide range of flow rates.

7.3 Recommendations

As was initially proposed for this work, FREEVU should be used in a case study to analyze a section of freeway that has recently been, or is currently being analyzed by the Planning and Design department of the MTO. This would provide valuable feedback regarding the suitability and clarity of the data input format and the output options currently available. Based on the feedback, modifications, if required, could be made to further enhance the interface design shell.

A number of modifications and enhancements have been identified, which would make FREEVU more accurate in modelling multilane freeway sections;

- enhance merging behaviour at high volumes.
- improve modelling of vehicles accessing off ramps.
- incorporate concepts of anticipation and driver's ability to look ahead.
- investigate how and/or if, the distribution of driver sensitivity changes over time and space.
- determine if effects of momentum should be modelled.
- determine grade effects on *normal* acceleration and deceleration rates.

It is also recommended that if and when these enhancements are made, that the simulation code currently written in FORTRAN, be translated in PASCAL so as to be consistent and compatible with the design shell code.

Furthermore, a computer programmer should be employed to rewrite portions of the code to fully exploit the new personal computer hardware capabilities (i.e. extended memory storage) and more efficiently handle data storage through use of a dynamic pointer structure. This would bring the program software up to commercial standards and allow the software to be widely distributed as an efficient design tool.

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Appendix A

Validation details

A.1 FHWA data and simulation results

Five sites were chosen from the 18 sites available from the FHWA data. A brief description, taken from reference [55], is provided for each site. A schematic of the site plan and geometric details are also provided. A summary of the data is provided along with simulation results. Comparisons are made, noting similarities and discrepancies, and conclusions are drawn. These comparisons and conclusions are summarized in the main body of Chapter 6.

FREEVU was used to simulate each of the 5 FHWA sites except I–295 as this site only had 2 minutes of observed data. As well, two simulations of the QEW were conducted — one of just the section visible from the surveillance camera and the second a 6 kilometre section from east of Hwy 403 to west of Mississauga Road. For each of these sites, results are presented in a similar format as for observations on the FHWA sites. It should be noted that more simulations were conducted than presented here — only the single run which was considered to represent the observed data most accurately in terms of traffic volumes and speeds is presented. These other runs were required to calibrate driver sensitivity to each site, and to determine the correct origin–destination matrix.

Site 1: I–295 Southbound between 11th street and Howard Road

This site is a weaving section created by the presence of an on-ramp followed by an off-ramp. The on-ramp adds a lane to the freeway which remains in place beyond the off-ramp. The on-ramp narrows from 2 lanes to one lane as it approaches the merge with the mainline. The heavy on-ramp volumes, and narrowing to one lane likely contributed to the rather low entry speeds observed in the data. As well, some merging vehicles merged into mainline traffic upstream of the designated merge area by cutting across the gore area.

Levels of service within the period filmed appeared to remain constant at D or E for weaving traffic and varied from B to D for mainline non-weaving traffic. Short but continuous queues were noted on the on-ramp throughout the filming period. A plan view of the section is presented in Figure A.1 and the aggregated observed data in Table A.1. Since only two minutes of observed data was available due to computer data retrieval difficulties, this site was not simulated.

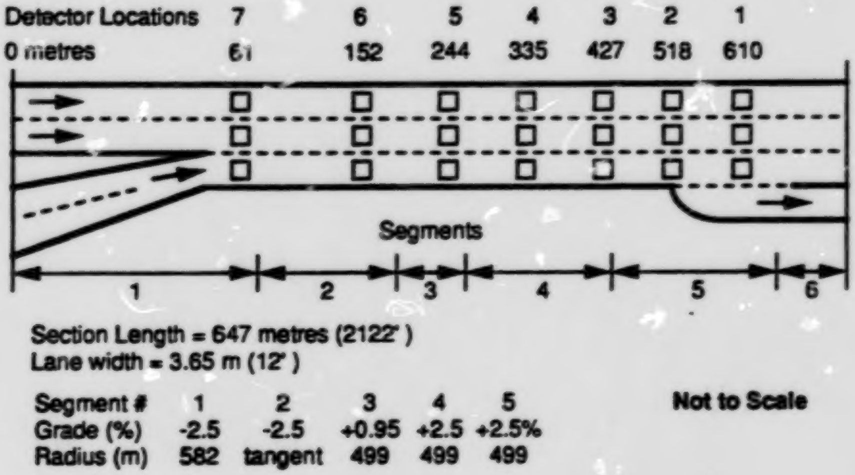

Detector Locations 7 6 5 4 3 2 1
0 metres 61 152 244 335 427 518 610
Segments
1
2
3
4
5
6
Section Length = 647 metres (2122')
Lane width = 3.65 m (12')
Segment # 1 2 3 4 5
Grade (%) -2.5 -2.5 +0.95 +2.5 +2.5%
Radius (m) 582 tangent 499 499 499
Not to Scale

Figure A.1: I-295 Southbound between 11th street and Howard Road

Table A.1: Aggregated observed data for I-295 Southbound

Total Observed Time = 2 minutes					
Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	1997	1392	1331	968
	Speed (km/h)	79.9	70.4	62.0	69.7
	% trucks	0.0	2.2	2.3	9.4
2	Volume (vph)	1876	1574	2300	
	Speed (km/h)	81.8	71.1	61.1	
	% trucks	0.0	1.9	6.6	
3	Volume (vph)	1846	1604	2209	
	Speed (km/h)	82.9	71.9	59.7	
	% trucks	0.0	0.0	9.6	
4	Volume (vph)	1786	1786	2088	
	Speed (km/h)	81.8	69.7	59.4	
	% trucks	1.7	0.0	7.2	
5	Volume (vph)	1907	1755	2179	
	Speed (km/h)	83.3	68.3	58.8	
	% trucks	1.7	0.0	6.9	
6	Volume (vph)	1816	1786	2179	
	Speed (km/h)	82.1	65.1	53.9	
	% trucks	1.7	0.0	5.6	

Site 2: I–95 Southbound at Backlick Road

This site consists of a single lane ramp merge. The site has three lanes, all on a 0.4% downgrade. Traffic was free-flow, ranging from an estimated level of service C to E. No queues extended outside of the section.

Approximately 5 minutes before the end of filming an incident occurred upstream of the section resulting in lighter flows within the section. Figure A.2 presents a schematic of the section. Simulation results are provided in Table A.2 and in the following discussion are compared to the first 19.5 minutes of observed data. Table A.3 provides the aggregated observed data. Note that the data has been aggregated into 3 summaries, each approximately 20 minutes in duration.

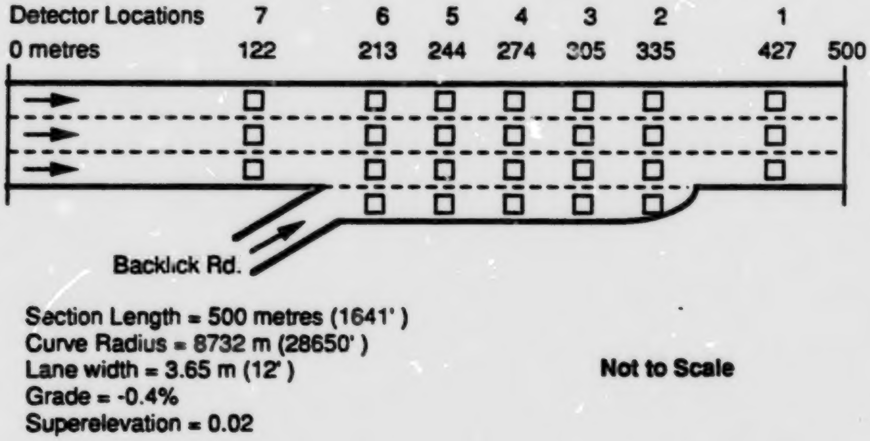

Detector Locations
7
6
5
4
3
2
1
0 metres
122
213
244
274
305
335
427
500
Backlick Rd.
Section Length = 500 metres (1641')
Curve Radius = 8732 m (28650')
Lane width = 3.65 m (12')
Grade = -0.4%
Superelevation = 0.02
Not to Scale

Figure A.2: I–95 Southbound at Backlick Road

Table A.2: Simulation results for Site 2: I–95 Southbound

Mean driver sensitivity = 0.729

Total Simulated Time = 20 minutes

Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	1680	1803	1890	
	Speed (km/h)	80	69	52	
	% trucks	7.1	5.8	7.7	
2	Volume (vph)	1638	1734	1740	243
	Speed (km/h)	78	63	46	64
	% trucks	7.1	6.2	7.4	4.9
3	Volume (vph)	1644	1740	1722	309
	Speed (km/h)	78	63	47	88
	% trucks	7.3	6.6	7.5	3.9
4	Volume (vph)	1614	1698	1785	321
	Speed (km/h)	76	62	48	94
	% trucks	7.2	6.9	7.6	3.7
5	Volume (vph)	1617	1677	1782	351
	Speed (km/h)	74	62	49	93
	% trucks	7.6	6.6	7.7	3.4
6	Volume (vph)	1584	1665	1767	396
	Speed (km/h)	73	61	47	89
	% trucks	7.4	5.9	7.6	3.8
7	Volume (vph)	1551	1620	1410	819
	Speed (km/h)	70	60	50	82
	% trucks	7.4	6.3	7.2	6.2

Table A.3: Aggregated observed data for I–95 Southbound

Total Observed Time = 19.5 minutes

Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	2155	2051	1900	
	Speed (km/h)	58.2	56.5	53.4	
	% trucks	5.3	6.1	8.9	
2	Volume (vph)	2131	1983	1940	24
	Speed (km/h)	55.8	53.4	50.7	50.1
	% trucks	5.2	6.3	8.4	12.5
3	Volume (vph)	2131	1940	1937	58
	Speed (km/h)	55.7	54.4	52.0	51.2
	% trucks	5.0	6.3	8.4	5.3
4	Volume (vph)	2128	1925	1873	125
	Speed (km/h)	56.2	55.5	53.9	55.5
	% trucks	5.2	6.7	8.2	4.9
5	Volume (vph)	2112	1922	1814	208
	Speed (km/h)	56.3	56.3	55.8	55.7
	% trucks	5.2	6.2	8.8	4.4
6	Volume (vph)	2112	1885	1649	393
	Speed (km/h)	56.8	56.5	57.3	58.7
	% trucks	6.4	6.4	8.6	5.5
7	Volume (vph)	2094	1793	1228	
	Speed (km/h)	54.9	56.2	63.5	
	% trucks	5.3	6.5	9.8	

As can be observed from the simulation and observed data, FREEVU consistently produces lower average lane volumes in the median lane than observed. In the centre and shoulder lanes, FREEVU produces results similar to those observed with the simulated volumes ranging from an under-estimation in the centre lane of 12.1%, to an over-estimation of 14.8% in the shoulder lane.

Speeds vary in the same manner as volumes — being higher than observed in the median lane, and very similar to observed in the shoulder lane.

Figure A.3 illustrates the location at which merging vehicles leave the ramp acceleration lane and enter the shoulder lane. A greater proportion of simulated merging vehicles are not able to merge until the end of the acceleration lane, than is observed. Examination of the simulation volumes recorded along the acceleration lane indicate that 52% of the vehicles entering the section via the ramp, merge with the mainline traffic stream prior to detector station #6. Of the remaining 48%, more than half, 29.5% of the total merging traffic, merge at the extreme end of the acceleration lane. Observed data indicates that 58% of the ramp vehicles merge before detector station #6, and only 2.6% merge at the end of the acceleration lane.

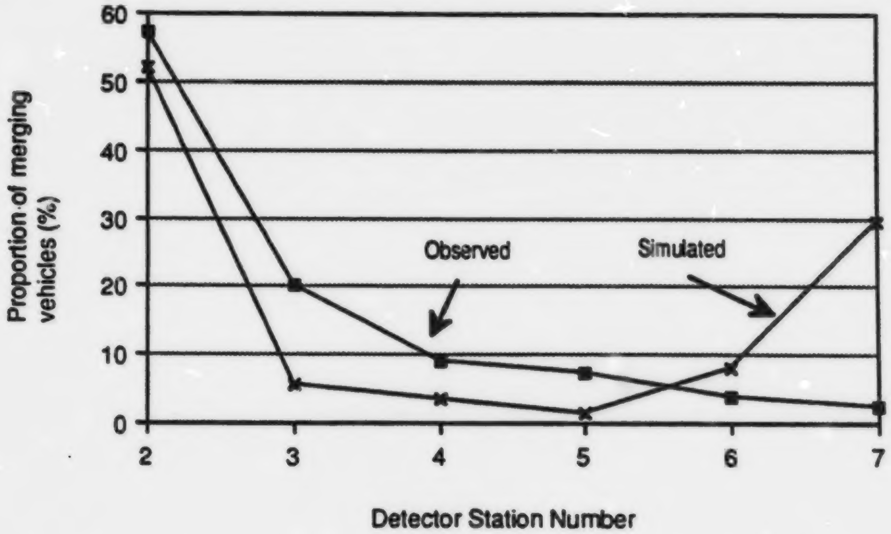


Figure A.3: Proportion of merging vehicles as a function of distance along acceleration lane

Two reasons may be cited to explain the noted differences in merging behaviour. The first is indicated by the average speeds recorded for vehicles travelling in the ramp lane. Simulation vehicles travel along the ramp in excess of 88 km/h until detector location #2, while the average speed in the adjacent shoulder lane is only approximately 47 km/h. In reality, the two adjacent traffic streams, the merging and mainline streams, have average speeds which are more similar, ranging from 57 km/h at the upstream end of the ramp merge section, to 50 km/h at the end of the acceleration lane.

In the simulation, when the mainline becomes congested, vehicles accessing the freeway via the ramp do not slow down to match their speed with that of the mainline vehicles. As the difference in speed between mainline and merging vehicles remains large, the merging vehicles require a greater gap for merging. Due to heavy flow in the shoulder lane, large gaps are not available. Unable to merge, the vehicles continue along the acceleration lane at a high speed until they approach the end of the lane, at which point they decelerate. Having come to a stop, the model initiates a forcing function so that merging vehicles are forced into the mainline stream. This causes the shoulder lane to stop and a queue to build moving upstream while the merging vehicles continue to force their way into the mainline stream at the head of the queue.

The second reason is the distribution of vehicles across the three mainline lanes. From the observed data, it seems that, upstream of the merge area, drivers prefer the median lane, even though at that point (detector #7) the average speed is considerably lower than that of the shoulder lane. However, the speed in the shoulder lane drops significantly along the length of the merge area, while the speeds in the centre and shoulder lanes remain virtually unaffected. This is illustrated more clearly in Figure A.4.

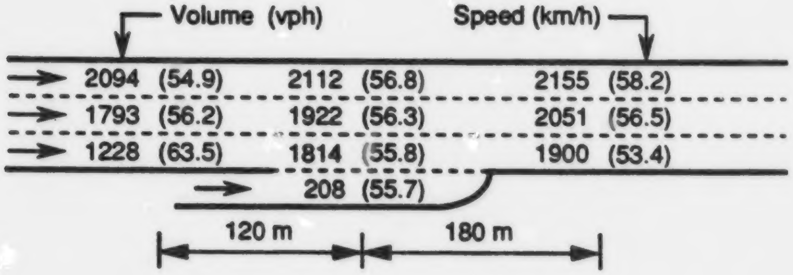


Figure A.4: Observed driver behaviour due to anticipation of ramp merge

The hypothesis is that drivers, aware of the downstream merging conditions, and anticipating the turbulence of the merging area, elect to move to the median and centre lanes. This anticipation ability provides for smoother flow and less breakdown as drivers are less *reactive* in their movements. Unfortunately, FREEVU has no ability to allow drivers to anticipate downstream conditions in this manner.

Despite these noted differences, FREEVU modelled the observed instability of the merging area well, with short queues forming and then dissipating in response to ramp merging flow fluctuations. The observed data, when viewed via the "movie" feature of FREEVU reflected these same characteristics.

Table A.3: Aggregated observed data for I–95 Southbound — continued

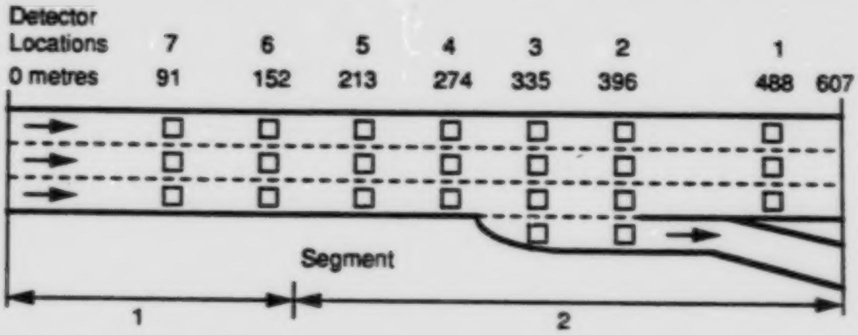
Total Observed Time = 20.4 minutes					
Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	2085	2011	1947	
	Speed (km/h)	61.6	59.7	55.5	
	% trucks	4.8	9.1	6.1	
2	Volume (vph)	2044	1976	2011	47
	Speed (km/h)	59.0	58.1	53.9	63.5
	% trucks	4.9	9.2	5.7	6.3
3	Volume (vph)	2032	1964	1994	91
	Speed (km/h)	58.9	59.0	53.6	59.2
	% trucks	4.8	9.1	5.9	6.5
4	Volume (vph)	2029	1917	1955	176
	Speed (km/h)	58.4	58.7	54.1	60.3
	% trucks	4.9	9.2	5.7	6.7
5	Volume (vph)	2011	1911	1820	332
	Speed (km/h)	58.7	59.2	56.3	60.0
	% trucks	5.0	9.2	5.8	5.3
6	Volume (vph)	2011	1900	1631	533
	Speed (km/h)	59.0	59.5	58.7	59.6
	% trucks	5.0	9.0	6.1	5.0
7	Volume (vph)	2020	1847	1225	
	Speed (km/h)	59.7	62.4	65.9	
	% trucks	5.0	8.9	8.2	

Table A.3: Aggregated observed data for I–95 Southbound — continued

Total Observed Time = 21.2 minutes					
Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	2008	1948	1880	
	Speed (km/h)	59.2	58.6	57.0	
	% trucks	3.1	8.7	5.7	
2	Volume (vph)	2011	1914	1861	79
	Speed (km/h)	55.5	58.2	58.6	57.6
	% trucks	3.1	8.9	5.9	0.0
3	Volume (vph)	2042	1883	1861	96
	Speed (km/h)	55.7	59.0	59.8	61.3
	% trucks	3.2	8.9	5.9	2.9
4	Volume (vph)	2053	1883	1778	170
	Speed (km/h)	56.2	59.2	61.4	62.4
	% trucks	3.2	8.9	6.1	3.3
5	Volume (vph)	2056	1900	1642	300
	Speed (km/h)	56.6	60.0	62.2	63.0
	% trucks	3.2	9.0	6.6	1.9
6	Volume (vph)	2068	1875	1438	519
	Speed (km/h)	56.5	60.3	63.4	62.6
	% trucks	3.3	8.8	7.1	2.2
7	Volume (vph)	2099	1858	1112	
	Speed (km/h)	58.9	64.2	69.6	
	% trucks	3.4	8.7	7.7	

Site 3: I–395 Southbound at Duke Street

This site consists of a three lane section on a 4.2% upgrade with an off-ramp located near the downstream end. Upstream of the site there exists a 3% down grade followed by a transitional vertical curve. As a result, momentum may affect speeds such that vehicles experience little speed reduction. A clover-leaf interchange was located approximately 300 metres downstream of the site. Level of service was estimated to be within the range of D to E. Figure A.5 illustrates the site plan while Table A.4 provides simulation results and Table A.5 presents the aggregated observed data.



Section Length = 607 metres (1991')
Lane width = 3.65 m (12')
Grade = +4.2%
Right shoulder = 3.05 m (10')
Left shoulder = 1.22 m (4')
Segment 1: Tangent
Segment 2: Radius = 1829 m (6000')

Not to Scale

Figure A.5: I–395 Southbound at Duke Street

Table A.4: Simulation results for Site 3: I–395 Southbound

Mean driver sensitivity = 0.560					
Total Simulated Time = 30 minutes [a]					
Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	1536	1578	1234	684
	Speed (km/h)	68	64	67	80
	% trucks	5.7	6.2	9.4	7.6
2	Volume (vph)	1556	1600	1216	686
	Speed (km/h)	65	58	58	66
	% trucks	6.0	6.2	8.7	7.9
3	Volume (vph)	1560	1666	1644	172
	Speed (km/h)	71	65	61	62
	% trucks	6.2	6.1	8.4	9.3
4	Volume (vph)	1574	1704	1776	
	Speed (km/h)	71	65	56	
	% trucks	6.5	6.6	8.1	
5	Volume (vph)	1578	1716	1762	
	Speed (km/h)	70	61	52	
	% trucks	6.7	6.5	7.8	
6	Volume (vph)	1580	1728	1746	
	Speed (km/h)	71	62	51	
	% trucks	6.6	6.4	7.7	
7	Volume (vph)	1592	1728	1746	
	Speed (km/h)	77	66	49	
	% trucks	7.2	6.6	7.6	

[a] Note that section was simulated with 2% grade instead of 4.2% in order to compensate for effect of momentum.

Table A.5: Aggregated observed data for I–395 Southbound

Total Observed Time = 60 minutes					
Detector #		Lane			
		Median	Centre	Shoulder	Ramp
1	Volume (vph)	2090	1823	1337	
	Speed (km/h)	65.1	65.0	62.9	
	% trucks	4.2	6.8	9.8	
2	Volume (vph)	2104	1856	1289	582
	Speed (km/h)	66.6	66.4	63.8	65.4
	% trucks	4.4	6.8	10.0	5.7
3	Volume (vph)	2106	1868	1374	482
	Speed (km/h)	67.2	67.2	63.7	64.6
	% trucks	4.4	6.9	9.9	5.4
4	Volume (vph)	2107	1879	1835	
	Speed (km/h)	67.0	67.2	62.9	
	% trucks	4.4	6.8	8.7	
5	Volume (vph)	2120	1869	1834	
	Speed (km/h)	66.2	66.7	62.6	
	% trucks	4.3	6.9	8.8	
6	Volume (vph)	2126	1877	1820	
	Speed (km/h)	66.6	66.9	63.4	
	% trucks	4.3	7.0	8.7	
7	Volume (vph)	2130	1885	1809	
	Speed (km/h)	67.0	67.7	64.0	
	% trucks	4.3	7.1	8.7	

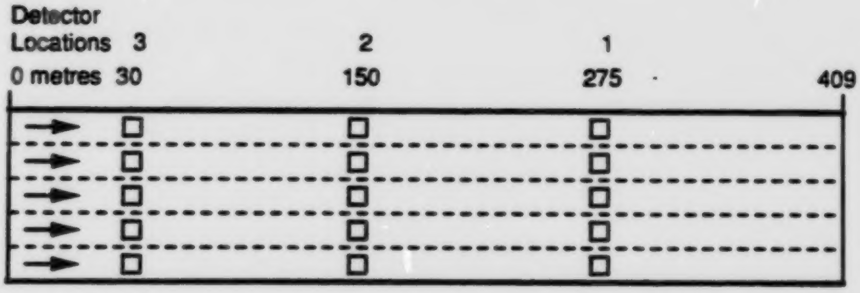
FREEVU models this section adequately, though total volumes are approximately 17% lower than observed. Examining individual average lane volumes, reveals that the greatest discrepancy occurs in the median lane where the simulated volume is 25% lower than observed at detector station #7 and 26.5% lower at station #1. The centre lane simulated volumes compare well with those observed, averaging approximately 8% lower than observed. Similarly, simulated volumes in the shoulder lane average approximately 4% lower than observed.

Average speeds also compare well, though simulation speeds in the shoulder lane tend to be lower than those observed, and in the median lane, higher than observed. These discrepancies are more pronounced in the shoulder lane at the upstream end of the section.

The discrepancies noted may be due to the presence of heavier trucks in the traffic stream than were present in observed data. Only the proportion of trucks in the traffic stream was available from the data set. No information concerning truck loadings was given, creating the possibility that the truck loadings used in the simulation were not representative of the data. As well, when the film was digitized, the operator determined which vehicles were trucks. Some error may have occurred at this stage. Unfortunately this could not be checked. As well, as noted in the site description, just upstream of the simulated section was a significant downgrade. This pronounced the momentum effect of vehicles such that speeds over the section were not significantly affected by the grade. To reflect this, the section was simulated using a 2% grade instead of the actual 4.2% grade which existed at the site.

Site 4: I–405 Northbound at Mulholland Drive

This site consists of a five lane section on a 3% upgrade. The site is located 800 metres from the top of a 4 km long grade. Traffic flow was estimated to be in the C to E range. Figure A.6 presents a schematic of the site. Table A.6 provides simulation results and Table A.7 presents the aggregated observed data.



Section Length = 409 metres (1341')
Tangent
Lane width = 3.35 m (11')
Grade = +3.0%
Right shoulder = 3.05 m (10')
Left shoulder = 1.22 m (4')

Not to Scale

Figure A.6: I–405 Northbound at Mulholland Drive

Table A.6: Simulation results for Site 4: I–405 Northbound

Mean driver sensitivity = 0.930						
Total Simulated Time = 24 minutes						
Detector #		Lane				
		Median	Centre	Centre	Centre	Shoulder
1	Volume (vph)	1657	1610	1490	1507	1370
	Speed (km/h)	85	71	59	50	51
	% trucks	0.5	3.4	10.6	8.1	17.2
2	Volume (vph)	1640	1562	1500	1530	1425
	Speed (km/h)	90	69	56	49	46
	% trucks	0.5	3.5	10.5	7.8	16.1
3	Volume (vph)	1585	1582	1512	1547	1460
	Speed (km/h)	95	77	57	51	47
	% trucks	0.6	3.9	10.4	8.2	14.9

Table A.7: Aggregated observed data for I–405 Northbound

Total Observed Time = 24 minutes						
Detector #		Lane				
		Median	Centre	Centre	Centre	Shoulder
1	Volume (vph)	2030	1794	1572	1441	984
	Speed (km/h)	86.4	81.6	80.0	76.8	75.2
	% trucks	3.9	4.8	6.2	10.2	15.9
2	Volume (vph)	2047	1823	1565	1503	914
	Speed (km/h)	86.4	81.6	78.4	75.2	73.6
	% trucks	3.9	4.6	5.6	10.6	16.6
3	Volume (vph)	1885	1667	1495	1438	872
	Speed (km/h)	84.4	80.0	76.8	75.2	73.6
	% trucks	4.1	4.6	6.0	10.9	17.7

FREEVU simulated this section quite well. Simulated total five lane volumes are only 2.4% lower than observed. The distribution of vehicles across lanes is not as well reflected, however, this is likely due to a difference in the truck population. As indicated in Table A.6, only 0.5% of the median lane volume is trucks, while Table A.7 indicates that the observed proportion of the median lane traffic stream is approximately 4%. It is hypothesized that the truck population used in the simulation contains heavier trucks than present in the observed data. These heavier trucks would be affected to a greater degree by the steep grade and experience a greater speed drop. These heavier trucks would also tend to move into the slower lanes — the shoulder and right centre lane. This shift can be identified in the simulation results.

Another factor supporting the hypothesis of different trucks streams is the average speeds recorded at each detector location. The simulation results indicate speeds for the median and left centre lane which are very similar to those observed. However, for the remaining three lanes, speeds are considerable lower than observed. Since the volumes in these lanes are not excessive, the low speeds must be due to poor truck performance. As this decrease is not as pronounced in the observed data, it seems likely that the observed traffic stream does not contain trucks which are as heavily loaded as used in the simulation. Had information regarding the truck population been available this hypothesis could have been rigorously tested.

Site 5: I–405 Southbound at Santa Monica Blvd.

This site consists of four lanes plus an on ramp, all on a short 3% downgrade. Traffic was free-flow for the first several minutes of the filming period, after which increased on-ramp flow caused flow to break down in the shoulder lane. This state of flow continued for the remainder of the filming period. Queuing began to extend outside of the section approximately 30 minutes after filming began.

There was a major freeway interchange located a short distance downstream of the site. Many of the vehicles traversing this site were preparing to exit to the right at the downstream interchange. Figure A.7 presents a schematic of the site and Table A.9 presents the aggregated observed data. Note that the data was aggregated into four separate groups of varying duration.

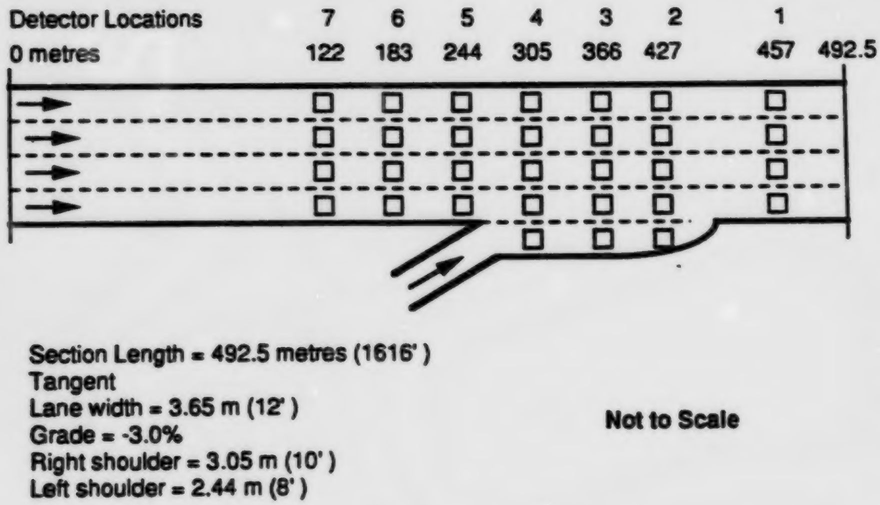

Detector Locations
7
6
5
4
3
2
1
0 metres
122
183
244
305
366
427
457
492.5
Section Length = 492.5 metres (1616')
Tangent
Lane width = 3.65 m (12')
Grade = -3.0%
Right shoulder = 3.05 m (10')
Left shoulder = 2.44 m (8')
Not to Scale

Figure A.7: I–405 Southbound at Santa Monica Blvd.

Table A.8: Simulation results for Site 5: I–405 Southbound

Mean driver sensitivity = 0.729						
Total Simulated Time = 30 minutes						
Detector #		Lane				
		Median	Centre	Centre	Shoulder	Ramp
1	Volume (vph)	1942	1754	1574	1548	
	Speed (km/h)	83	66	49	35	
	% trucks	8.7	11.5	12.2	14.9	
2	Volume (vph)	1960	1746	1574	1562	
	Speed (km/h)	80	61	41	18	
	% trucks	8.5	11.2	11.8	14.7	
3	Volume (vph)	1928	1732	1392	798	976
	Speed (km/h)	75	54	31	15	65
	% trucks	8.5	11.3	12.4	13.8	13.9
4	Volume (vph)	1910	1676	1348	908	992
	Speed (km/h)	72	51	30	17	101
	% trucks	8.5	11.8	12.2	13.2	14.1
5	Volume (vph)	1876	1666	1354	976	1002
	Speed (km/h)	71	53	32	22	106
	% trucks	8.5	11.9	12.1	12.1	14.2
6	Volume (vph)	1830	1674	1330	1048	
	Speed (km/h)	69	54	34	26	
	% trucks	8.5	11.8	11.9	12.0	
7	Volume (vph)	1798	1650	1342	1094	
	Speed (km/h)	69	54	40	28	
	% trucks	8.9	11.8	12.1	11.3	

Table A.9: Aggregated observed data for I–405 Southbound

Total Observed Time = 14 minutes						
Detector #		Lane				
		Median	Centre	Centre	Shoulder	Ramp
1	Volume (vph)	2133	1910	2211	2163	
	Speed (km/h)	79.3	71.5	58.8	50.3	
	% trucks	11.1	11.2	15.0	11.9	
2	Volume (vph)	2116	1897	2120	2279	8
	Speed (km/h)	75.4	70.4	57.7	47.1	52.0
	% trucks	11.0	11.1	15.0	12.1	0.0
3	Volume (vph)	2086	1880	1992	2249	240
	Speed (km/h)	72.6	67.8	55.3	39.7	41.7
	% trucks	11.1	11.4	14.9	11.5	17.9
4	Volume (vph)	2090	1876	1777	1807	905
	Speed (km/h)	70.2	64.3	53.5	36.1	36.6
	% trucks	11.1	11.4	15.9	9.3	16.6
5	Volume (vph)	2030	1884	1764	1382	437
	Speed (km/h)	68.6	63.2	51.8	39.4	32.7
	% trucks	10.8	11.6	15.6	8.1	15.7
6	Volume (vph)	2000	1880	1747	1442	
	Speed (km/h)	69.4	64.0	52.2	43.5	
	% trucks	10.3	13.2	14.7	8.0	
7	Volume (vph)	1871	1828	1713	1472	
	Speed (km/h)	70.7	65.6	54.6	49.7	
	% trucks	10.6	13.8	14.8	8.5	

Table A.9: Aggregated observed data for I–405 Southbound — continued

Total Observed Time = 13.25 minutes						
Detector #		Lane				
		Median	Centre	Centre	Shoulder	Ramp
1	Volume (vph)	2045	1950	2112	2085	
	Speed (km/h)	72.8	66.7	56.2	47.3	
	% trucks	6.8	7.9	12.6	10.4	
2	Volume (vph)	2045	1896	2081	2153	4
	Speed (km/h)	71.5	65.0	54.0	42.6	62.4
	% trucks	6.8	7.9	13.0	10.1	0.0
3	Volume (vph)	2027	1873	1855	2126	243
	Speed (km/h)	68.2	61.7	50.1	34.4	38.1
	% trucks	6.9	8.0	13.1	9.3	16.7
4	Volume (vph)	2018	1855	1747	1715	799
	Speed (km/h)	66.4	58.4	46.6	28.0	33.9
	% trucks	6.9	7.8	13.4	9.7	10.7
5	Volume (vph)	2004	1864	1670	1413	744
	Speed (km/h)	66.2	57.8	43.1	29.1	32.6
	% trucks	7.4	7.0	13.2	9.6	12.1
6	Volume (vph)	1959	1869	1634	1462	
	Speed (km/h)	67.3	57.8	41.9	33.9	
	% trucks	7.4	7.0	13.8	9.6	
7	Volume (vph)	1878	1765	1665	1512	
	Speed (km/h)	70.1	61.4	46.9	43.8	
	% trucks	7.5	6.4	14.1	9.3	

Since queuing began to extend outside of the section 30 minutes after filming began, and flow in the shoulder broke down after the first few minutes, the simulation results will only be compared to the second table of Table A.9, representing 13.25 minutes of observed data.

The simulation results indicate that at the upstream end of the section, simulated total four lane volumes are 13.7% less than observed, with the largest discrepancies occurring in the shoulder and right centre lanes. Average simulation speeds are similar to those observed for the median lane, but are increasing lower than observed moving to the shoulder lane.

The effect of the major junction downstream of the site on the traffic flow is unknown, however, the data indicates that a significant number of vehicles occupying the shoulder and right centre lane downstream of the merge area were preparing to exit the freeway. As no data concerning the junction, other than that it existed, was available, this site was difficult to define appropriately for the simulation. Traffic behaviour resulting from the junction was not able to be modelled, making conclusive comparisons difficult.

Some concern was raised over the proportion of trucks in the observed traffic stream. Errors in digitizing the aerial photographs seem possible, as it seems unlikely, even on a -3% downgrade, that lane volumes in excess of 2100 vph can be maintained in an ramp merge area with 10% trucks in the traffic stream as is indicated by the observed data for the shoulder lane.

The observed data was viewed using FREEVU's "movie" capabilities, providing the following observations. From subjective visual evaluation, it appears that drivers were accepting very small separation distances. It was hypothesized that due to the 3% down grade, drivers had greater visibility of downstream events and thus accepted smaller separation distances than they normally would. This was particularly true for drivers in the merging area, where headways were consistently short, permitting the maintenance of flows in excess of 2000 vph. Flow in the merging area remained constant with minor queues forming briefly and then dissipating.

The simulation results, when viewed, produced similar breakdown characteristics with queues forming temporarily, however, it was clear that this occurred at lower volumes than observed.

This simulation demonstrates that FREEVU is capable of simulating breakdown adequately, though this occurs at somewhat lower volumes than observed. Speeds in the merging area are consistently lower than observed, likely due to the model's inability to reflect drivers capacity to reduce their headway when their visibility is increased. Some uncertainty exists as to the effect of the downstream junction on the traffic stream behaviour.

Table A.9: Aggregated observed data for I–405 Southbound — continued

Total Observed Time = 6 minutes						
Detector #		Lane				
		Median	Centre	Centre	Shoulder	Ramp
1	Volume (vph)	2098	1936	2068	2139	
	Speed (km/h)	71.4	66.3	53.1	45.5	
	% trucks	3.9	5.2	11.3	12.8	
2	Volume (vph)	2088	1916	1946	2261	0
	Speed (km/h)	69.8	64.6	50.8	41.3	—
	% trucks	3.9	5.3	10.4	13.5	—
3	Volume (vph)	2119	1835	1845	2159	263
	Speed (km/h)	66.0	60.3	46.4	31.3	35.0
	% trucks	3.8	5.5	9.9	13.6	11.5
4	Volume (vph)	2078	1814	1723	1693	861
	Speed (km/h)	62.9	56.4	42.1	26.9	30.5
	% trucks	3.4	4.5	11.8	10.2	18.8
5	Volume (vph)	2048	1835	1652	1439	532
	Speed (km/h)	60.7	53.2	36.9	26.9	37.2
	% trucks	3.0	5.0	12.9	7.0	22.6
6	Volume (vph)	2017	1845	1622	1490	91
	Speed (km/h)	59.5	51.4	36.7	28.6	53.7
	% trucks	3.0	4.9	11.9	8.2	22.2
7	Volume (vph)	1987	1835	1612	1490	
	Speed (km/h)	60.1	53.4	37.0	33.1	
	% trucks	2.6	5.0	12.6	8.2	

Table A.9: Aggregated observed data for I–405 Southbound — continued

Total Observed Time = 11.9 minutes						
Detector #		Lane				
		Median	Centre	Centre	Shoulder	Ramp
1	Volume (vph)	2016	1960	2112	2132	
	Speed (km/h)	72.2	64.9	51.3	45.2	
	% trucks	3.3	6.2	10.3	7.8	
2	Volume (vph)	1991	1981	2051	2218	5
	Speed (km/h)	70.7	63.4	49.1	41.2	11.2
	% trucks	3.3	6.1	9.8	8.2	0.0
3	Volume (vph)	2001	1894	1940	2182	231
	Speed (km/h)	67.9	60.6	45.8	33.7	36.6
	% trucks	3.3	5.9	10.4	7.6	8.7
4	Volume (vph)	1966	1890	1769	1774	826
	Speed (km/h)	65.1	56.9	41.6	26.5	30.7
	% trucks	3.3	5.6	10.3	8.0	8.5
5	Volume (vph)	1955	1874	1708	1285	80
	Speed (km/h)	62.8	53.7	37.0	24.1	27.6
	% trucks	3.4	5.6	10.6	7.5	12.5
6	Volume (vph)	1920	1860	1668	1376	
	Speed (km/h)	61.0	51.9	34.9	28.1	
	% trucks	3.4	5.4	10.6	7.3	
7	Volume (vph)	1885	1839	1603	1456	
	Speed (km/h)	58.2	50.2	36.9	33.1	
	% trucks	3.5	5.5	11.0	6.6	

Manoeuvre rates observed on QEW

This site consists of a three lane section having no appreciable grade. The site is located approximately 2 kilometres from any upstream or downstream ramps. Table A.10 presents the aggregated observed manoeuvre rates used to develop the regression equation presented in the text.

Table A.10: Manoeuvres rates per vehicle kilometre observed on QEW

Time	Volume[a]	Manoeuvres		Manoeuvre Rates		
(a.m.)	(vph)	Left	Right	Left	Right	Total
7:55	3988	6	4	0.030	0.020	0.050
8:10	4040	10	7	0.050	0.035	0.084
8:25	4332	4	2	0.018	0.009	0.028
8:40	4168	2	10	0.010	0.048	0.058
8:55	4240	2	14	0.009	0.066	0.075
9:10	4012	9	7	0.045	0.035	0.080
9:25	3824	8	3	0.042	0.016	0.058
9:40	3696	14	6	0.076	0.032	0.108
9:55	surveillance camera failure					
10:10	3440	8	5	0.047	0.029	0.076
10:25	3276	16	10	0.098	0.061	0.159
10:40	3300	13	7	0.079	0.042	0.121
10:55	3436	14	8	0.081	0.047	0.128
11:10	2928	18	6	0.123	0.041	0.164
11:25	3139	19	10	0.121	0.064	0.185
Avg	3679	10.54	7.31	0.061	0.040	0.102
std	431.70	5.41	3.08	0.037	0.017	0.046

[a] Total 3 lane volumes.

Only the one hour period beginning at 10:25 a.m. was simulated for manoeuvre rate comparison purposes. As illustrated in Figure A.8, the section simulated consisted of three lanes on a tangent section. Observed and simulated data is presented in Table A.11. Note that observed speed data was not available.

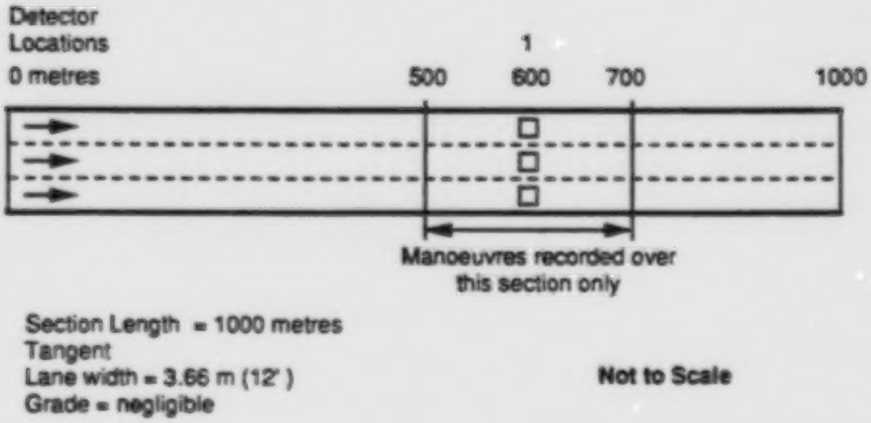

Detector
Locations
1
0 metres
500
600
700
1000
Manoeuvres recorded over
this section only
Section Length = 1000 metres
Tangent
Lane width = 3.66 m (12')
Grade = negligible
Not to Scale

Figure A.8: QEW site on which manoeuvre rates simulated

Table A.11: Simulation and observed data: QEW manoeuvre section

Simulation mean driver sensitivity = 0.560						
Total Simulated Time = 60 minutes						
Total Observed Time = 60 minutes						
	Observed			Simulation		
	Median	Centre	Shoulder	Median	Centre	Shoulder
Volume (vph)	1196	1312	727	1068	1079	1152
Speed (km/h)	n.a.	n.a.	n.a.	107	105	105
% trucks[a]	1.9	41.9	56.2	0.0[b]	16.5	21.4

[a] Observed data includes buses for % truck calculation.

[b] For simulation the median lane is restricted to trucks.

General data analysis

In attempting to more fully understand the nature of the observed traffic stream behaviour, a closer analysis of the FHWA data was made. The data format of the FHWA data was altered to conform to FREEVU and two 10 minute segments of the data for sites 3 and 5 were viewed. This ability to view the microscopic flow dynamics greatly increased the value of the data and provided a clear and immediate picture of what was actually occurring on the freeway.

Based on FHWA data observed on FREEVU, commuter traffic appears to be composed of a more homogeneous driver population than non-commuter traffic. Commuter traffic also tends to be more aggressive and as a population, consistently accepts smaller headways than non-commuter traffic. To reflect this in the simulation, the driver headways were reduced by modifying *k*. It was thought that being more homogeneous, the variation in headways within the population would also be reduced (Figure A.9). If this is true, then it would imply better flow as breakdown tends to occur due to random extremes. In addition, driver aggression may change across lanes, with drivers in the median lane being more aggressive than those in the shoulder lanes. The effect of reducing the variance of driver aggression was not modelled.

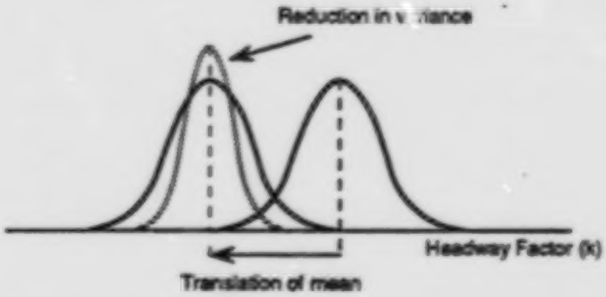


Figure A.9: Effect of driver type on distribution of driver sensitivity

From the FHWA data, mainline vehicles seem to accept, at least temporarily, an *unsafe* position when a merging vehicle moves in front of it (an *unsafe* position being one in which the following vehicle will be unable to avoid a collision if the lead vehicle decelerates at its maximum rate). This implies smaller headways and greater flow. This behaviour has been observed elsewhere and noted in the literature, however, it is not yet a fully understood phenomenon [57].

With a disciplined, homogeneous driver population, as seems to exist during commuting peaks, this type of flow can be sustained and remain rather stable. Since FREEVU is based on collision avoidance algorithms, the model does not permit this (except during the time required for a lane change to occur). It should be noted that this behaviour was only observed at ramp merge situations, but no quantitative study was carried out.

A.2 Vehicle data file

The vehicle data file contains all of the information necessary to define a vehicle's length, desired speed and operating characteristics in terms of power, mass, and frontal area, and its probability of appearing in the traffic stream.

Currently, the data file specifies 6 car classes and 3 truck classes (Table A.12). There are 3 vehicles within each class. The 6 car classes and their characteristics were determined from consumer survey literature [49]. Within each class, the three vehicle types are identical except that each has a different desired speed and driver aggressiveness. This represents some distribution of driver types within each vehicle class.

The 3 truck classes represent tandem axle straight trucks, tandem axle tractor with tandem axle trailer, and tandem axle tractor with tandem axle double trailers. The three vehicle types within each of these three classes represent different loadings — empty, 50% and fully loaded. *Load* here refers to weight not volume, so a fully loaded truck is at its maximum legal weight. Truck data was obtained from a commercial vehicle survey conducted by the MTO in 1983 throughout the province of Ontario [48], and from technical specifications for various truck configurations obtained from truck manufactures.

Tables A.13 and A.14 present the current vehicle characteristics.

Table A.12: Current vehicle classes

Class	Description
1a	Small Car
1b	Sporty Car
1c	Compact Car
1d	Medium Car
1e	Large Car
1f	Vans
2	Tandem axle straight truck
3	Tandem axle tractor with tandem axle trailer
4	Tandem axle tractor with 2 tandem axle trailers

Table A.13: Vehicle data file — car data

Veh #	Class	HP	GVM (kg)	Area (m^2)	Length (ft)	z_i [a]	$P()$ [b] (%)	k [c]
1	1a	70	1125	2.1	14	-0.141	12.0	0.8
2	1a	70	1125	2.1	14	-0.922	6.0	1.0
3	1a	70	1125	2.1	14	-1.444	4.0	1.3
4	1b	125	1370	2.0	14	1.944	2.0	0.6
5	1b	125	1370	2.0	14	0.120	5.0	0.8
6	1b	125	1370	2.0	14	-0.401	6.0	1.0
7	1c	110	1375	2.1	15	2.986	1.0	0.7
8	1c	110	1375	2.1	15	1.162	10.0	0.9
9	1c	110	1375	2.1	15	-0.662	8.0	1.1
10	1d	125	1545	2.3	16	0.641	9.0	0.8
11	1d	125	1545	2.3	16	-0.141	8.0	0.9
12	1d	125	1545	2.3	16	-2.225	3.0	1.0
13	1e	140	1745	2.5	17	3.508	0.5	0.8
14	1e	140	1745	2.5	17	1.162	8.0	0.9
15	1e	140	1745	2.5	17	-1.444	5.0	1.1
16	1f	105	1680	3.1	15	0.641	5.0	1.1
17	1f	105	1680	3.1	15	-0.141	4.5	0.9
18	1f	105	1680	3.1	15	-0.922	3.0	0.8

[a] Normal standard deviate of desired speed — Section 5.3

[b] Probability of vehicle appearing in stream.

[c] Driver sensitivity — Section 5.1.1

Table A.14: Vehicle data file — truck data

Veh #	Class	HP	GVM (kg)	Area (m^2)	Length (ft)	z_i [a]	$P()$ [b] (%)	k [c]
62	2	275	9000	7.5	35	0.380	9.6	0.8
63	2	275	18500	7.5	35	-0.401	3.6	1.0
64	2	275	28000	7.5	35	-1.183	10.8	1.2
82	3	330	14500	8.0	60	0.380	28.0	0.9
83	3	330	30850	8.0	60	-0.141	11.0	1.1
84	3	330	47200	8.0	60	-0.922	32.0	1.3
92	4	400	18750	8.0	75	-0.401	2.0	1.0
93	4	400	41000	8.0	75	-1.444	0.8	1.2
94	4	400	63000	8.0	75	-2.486	2.2	1.5

[a] Normal standard deviate of desired speed — Section 5.3

[b] Probability of vehicle appearing in stream.

[c] Driver aggressiveness — Section 5.1.1.

Appendix B

Technical program documentation

B.1 Simulation program subroutine documentation

Only the simulation module of FREEVU is discussed here. Subroutines are listed alphabetically. Previous documentation provides a more detailed description of the simulation module as it existed in the FOMIS model [58]. Figure B.1 illustrates the module's computing structure in flowchart form. A brief description of the function of each subroutine follows.

Acclead determines the deceleration required by the following vehicle to avoid colliding with the leading vehicle, when the leading vehicle decelerates at maximum deceleration. The purpose is to prevent lane changing vehicles from entering into an *unsafe* position whereby if the leading vehicle were to decelerate at maximum deceleration, the following vehicle could not avoid a collision.

Accel determines the maximum acceleration which the current vehicle can achieve given the vehicle's current velocity, the grade the vehicle is currently operating on, and the vehicle's power and weight characteristics.

Check determines if a lane change manoeuvre is possible. The routine begins the check by determining the acceleration (or deceleration) required for the lane changing vehicle to successfully enter the gap (Figure B.2). This acceleration is checked to ensure that the vehicle type making the manoeuvre can achieve this acceleration. If this acceleration is acceptable, then the acceleration of the new following vehicle (MR) is determined and check for validity. If a lane change is

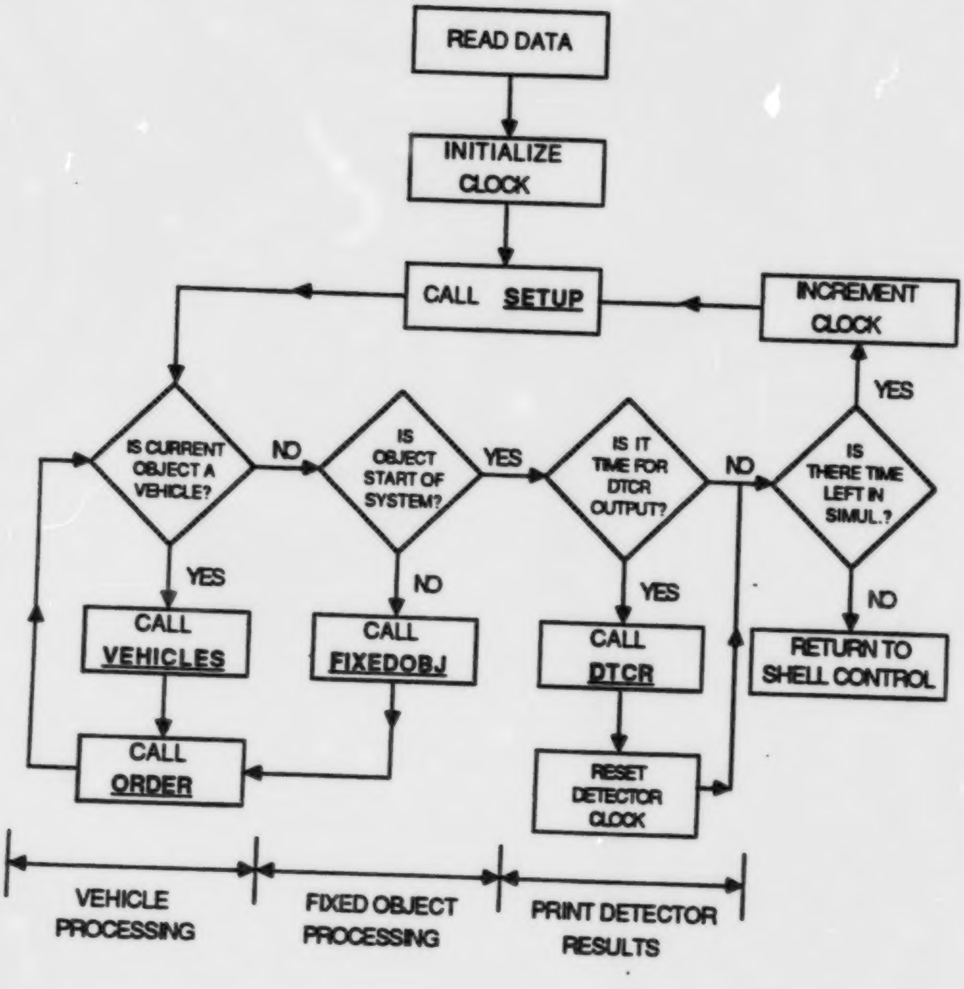

READ DATA
INITIALIZE CLOCK
CALL SETUP
INCREMENT CLOCK
IS CURRENT OBJECT A VEHICLE?
NO
IS OBJECT START OF SYSTEM?
YES
IS IT TIME FOR DTCR OUTPUT?
NO
IS THERE TIME LEFT IN SIMUL.?
YES
YES
CALL VEHICLES
NO
CALL FIXEDOBJ
YES
CALL DTCR
NO
RETURN TO SHELL CONTROL
CALL ORDER
RESET DETECTOR CLOCK
VEHICLE PROCESSING
FIXED OBJECT PROCESSING
PRINT DETECTOR RESULTS

Figure B.1: Flowchart of simulation module program structure

possible then the lane change is made and all arrays are updated to reflect this manoeuvre.

Note that a lane changing manoeuvre has a user specified duration (typically 3 seconds) during which time the vehicle need not be in a *safe* position. As well, a vehicle engaged in a lane change can only move ahead until the lane change is completed.

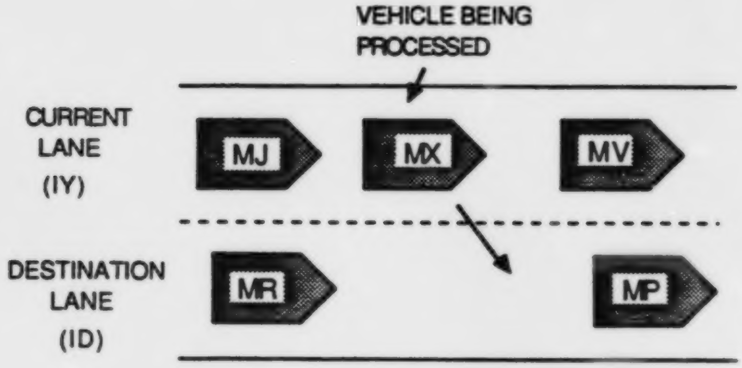


Figure B.2: Lane change mechanics

Desired determines if a driver *desires* to make a lane change as opposed to a *mandatory* lane change.

Dtcr writes detector data to the simulation data file `filename.SIM`. Data is not recorded during the *fill up* period. This routine also does the calculations necessary to produce average detector output for the entire simulation period.

Note that detector output written to the `filename.SIM` is in imperial units, density in v/mi and speed in mph.

Emrgncy contains the collision avoidance algorithm for emergency braking.

FixedObj processes fixed objected, taking appropriate action based on the object type encountered. If the fixed object defines the beginning of the system or an on-ramp, then routine **Generate** is evoked. If the object defines a lane or physical section boundary, then the counter containing the current section is updated.

FMove is invoked to determine the acceleration or deceleration of the current vehicle during the current time interval. This rate is determined from the basic collision avoidance car following algorithm discussed in Chapter 5.

Once the acceleration rate for the time interval has been determined from the car following algorithm based on the lead vehicle's current position, speed and acceleration, a check is made to ensure that a collision can be avoided if the lead vehicle were to decelerate at its maximum deceleration rate.

When an acceleration rate is determined which prevents any conflicts with the lead vehicle, routine **Movit** is invoked to deal with the details of moving the vehicle.

Follow determines if a vehicle following some other vehicle, will decelerate to maintain a safe distance headway.

Generate generates vehicles at the start of the freeway section and at the start of any on-ramps. The vehicle types are generated according to their assigned probability of occurring found in the data file `DATA.VEH`. Having determined the generated vehicle's type, the following characteristics , being functions of the vehicle type, are also known:

- Desired speed based on the current speed limit.
- Power and weight characteristics.
- Vehicle length.
- Maximum comfortable (non-emergency) deceleration.

All of these characteristics are stored in the data file `DATA.VEH` and can be altered by the user.

Once a vehicle type is generated, a space headway required to place the vehicle is also generated. This space headway is generated according to a shifted negative exponential distribution.

Should the generated vehicle require a space headway greater than that currently available, this vehicle is placed in a buffer until such time as there is a large enough headway to accommodate it.

The vehicle's destination number is determined based on the Origin-Destination matrix specified in the data file `filename.GEO`.

Movit calculates the new position and speed of the vehicle based on the desired acceleration (based on car following logic) and the maximum attainable acceleration (based on the vehicle's characteristics, current grade and speed). This routine is called from either **Check**, signifying that a lane change has been accomplished, or **FMove**, implying that the vehicle is simply moving ahead in the current lane.

Order determines which lane contains the next upstream vehicle or object requiring processing.

Passing contains the driver lane changing decision algorithms. These decision algorithms are only applicable to behaviour initiated lane changes. The end result from this routine is the decision to make or not make, a lane change.

Random returns an integer random number in the range of 1 to 100.

Read gathers all the necessary data for defining the section, the simulation controls, and the vehicle characteristics from the files on disk.

Required determines if a lane change is required by the current vehicle before the end of the current physical section. If a lane change is required (i.e. a vehicle is in an acceleration lane and must make the lane change before the end of the acceleration lane), then the vehicle will attempt a lane change. If a lane change is not possible, and the vehicle is approaching the point by which a lane change must be made, then the vehicle will begin to decelerate and will eventually come to a stop while continually attempting to make the lane change.

It should also be pointed out, that as the distance to the point by which the lane change must be made, decreases, the vehicle will become more aggressive and less particular about acceptable gap sizes.

In terms of programming code, a mandatory lane change is deemed to be required when the vehicle's destination number is either less than the low flag of the mandatory matrix for the current lane and physical section (lane change to the *left* is required), or if the destination number is greater than the high flag of the matrix (lane change to the *right* required).

Risk models the increasingly extreme actions a driver is willing to take as the distance over which a lane change can be made, decreases.

Setup determines, at the beginning of each simulation interval, the lane containing the furthest downstream object or vehicle.

Timegap calculates the time required for a following vehicle to overtake a leading vehicle based on the vehicles' current speed, acceleration, length, and initial position. Since it assumed that acceleration is constant over the time interval, simple equations of motion can be used to describe the vehicle's movement. This routine is used to evaluate the desirability of potential lane changes.

Vehicles controls all vehicle movements and lane changes. This routine acts as the controller for all of the other routines involved in vehicle movements.

Write compiles, formats and writes all selected output to disk.

Zero resets all necessary counters after each time period.

B.2 General variable listing

The following is a listing of all of the general variables used throughout the simulation core of FREEVU. The list is presented in 4 sections;

1. single variables,
2. one dimensional arrays,
3. two dimensional arrays, and
4. three dimensional arrays.

In each section the variables are listed in alphabetical order.

B.2.1 Single variables

IGRAD	Percent grade of current section.
IH	Binary variable to check status of lane change: IH=1: lane change was achieved. IH=0: lane change was not possible.
IJ1	User specified time in seconds during which FREEVU does not record any results.
IK	Current physical section number.
IL	Current lane section number.
IM	Time period interval number.
IMTOT	Total number of intervals specified
IN	Lane change duration (scans).
IP	Percent of courteous drivers.

IR	Flag to indicate the reason for, and direction of, the lane change. IR=0: no lane change. IR=1: pass on the left to increase speed. IR=2: pass on the right to increase speed. IR=3: yield because veh. can't maintain current speed. IR=4: desired lane change. IR=5: mandatory lane change. IR=6: yield because veh. is impeding following vehicle.
IRNU	Random integer number between 1 and 100.
IS	Elapsed clock time in seconds including *fill up* time.
IT	Clock, number of scanning intervals including IJ1.
IU	Clock for detector output.
JF	Total number of exits from the system, including ramps.
JG	Total number of entrances on the system.
JM	Number of physical section.
JN	Number of lane sections.
KA	Lag time for acceleration.
KB	Lag time for deceleration.
KES	Time in seconds over which accel. takes place.
KET	Time in scans over which accel. takes place.
KI	Scanning interval in tenths of a second.
KF	Car following factor.
KO	Forced lane change indicator: KO = 0: no change required, KO > 0: forced change is required. The value of KO equals the X-coord. of the end of the current physical section.
KS	Distance of *risk* effect = maximum of 1500 feet.
KT	Total simulation time in scanning periods including IJ1.
KXXB	Distance traveled by vehicle during interval (ft).
LAG	Accel. lag time.
LRSTRCT	Lane number restricted to truck.
MAXC	Total number of vehicle classes (max 6).
MD	Maximum vehicle deceleration ($10 \mathrm{x ft/s^2}$).
MF	Total number of fixed objects.
MG	Total number of detectors locations.
MI	Total number of incidents.
ML	Total number of lanes.
MO	Generated vehicle number.
MT	Time interval in scans between detector output.

NUMCARS	Number of vehicles to be generated (if = 0 then no limit).
SMC	Relates mean desired speed to posted speed = 1.10.
ZB	Normal variate coefficient to alter speed variance = 0.09.

B.2.2 One dimensional arrays

IVTC(I)	vehicle class of vehicle type I (max 6 classes).
IMSIM(I)	I=1: Start time for recording animation data. I=2: Time at which to stop recording animation data.
IMTIME(I)	End time of time period I (sec).
JPER(I)	Percent trucks in the traffic stream during interval I.
KLD(I)	Clock time since the last vehicle was place at generation point I.
KST(I)	Specified segment over which lane changes are recorded: I=1: upstream boundary of segment (feet). I=2: downstream boundary (feet).
KTV(I)	Clock time when vehicle I was placed on the freeway.
LD(I)	X-coordinate of the downstream end of physical section I.
LF(I)	Follower in lane I.
LL(I)	Leader in lane I.
LN(I)	Length of vehicle type I.
LU(I)	Detector speed for lane I (in km/h).
LV(I)	Detector volume for lane I (in vph).
LW(I)	Detector occupancy for lane I (density in v/km).
LX(I)	Ranked order of lanes containing objects to be processed. LX(1) = 4 means first object to be processed is in lane 4.
MAC(I)	Maximum comfortable acceleration rate for velocity range I.
MACC1(I)	Vehicle I's accel. rate (x10).
MDC(I)	Maximum comfortable decel. rate for velocity range I.
NF(I)	Driver sensitivity (x10) corresponding to vehicle I.
NJ(I)	Jerk applicable to vehicle type I (constant: = 40).
NP(I)	% probability of vehicle type I occurring in the traffic stream.
NP1(I)	Relative % probability of vehicle type I occurring relative to the other cars, if vehicle type I is a car, or trucks, if I is a truck.
SA(I)	Vehicle speed (real) in ft/s.
Z(I)	Normal sandard speed deviate of vehicle I.

B.2.3 Two dimensional arrays

IGEN(I,J)	Characteristics of the next vehicle to be placed in lane I. J = 1: vehicle number J = 2: vehicle type J = 3: required spatial headway.
JCHANGE(I,J)	The number of lane changes made in each of 23 categories: I=1: pass on the left. I=2: pass on the right. I=3: yield right because vehicle can't maintain speed. I=4: mandatory change to the left. I=5: mandatory change to the right. I=6: desired change to the left. I=7: desired change to the right. I=8: frustration factor. I=9: yield right because vehicle is impeding follower. J=1: encounters with screening logarithm. J=2: successful passing of criteria. J=3: actual lane changes made.
JGEN(I,J)	Number of vehicles generated at each generation point J. I=1: all vehicles. I=2: just trucks.
JVOL(I,J)	Sum of volumes recorded by detector I, in lane J.
LC(I,J)	Lane type for lane J, physical section I.
LI(I,J)	% of lane J blocked during incident in physical section I.
LJ(I,J)	Controls mandatory moves. Lowest destination lane permitted for vehicle in lane J, physical section I.
LK(I,J)	Highest destination lane.
LM(I,J)	Desired lane volume for entrance point J, time period I.
LS(I,J)	% vehicles entering section by ent. # I to leave via exit # J.
LSPEED(I,J)	Posted speed limit in lane I, section J (ft/s).
NN(I,J)	Copy of original position of fixed objects relative to object I. J=1: following (upstream) object number. J=2: leading (downstream) object number.

Vehicle array

N(I,1)	X-coordinate of vehicle I (ft).

N(I,2)	Type of vehicle I.
N(I,3)	Next upstream object/vehicle behind vehicle I.
N(I,4)	Entrance number vehicle generated at.
N(I,5)	Acceleration of I (ft/s2).
N(I,6)	Time (sec) since vehicle I began a lane change. Value positive if change to right, else negative.
N(I,7)	Exit number that vehicle I must exit from.
N(I,8)	Next downstream object/vehicle in front of vehicle I.

Fixed object array

N(I,1)	X-coordinate of object I.
N(I,2)	Type of object I.
N(I,3)	Next upstream object/vehicle behind object I.
N(I,4)	Number of object (i.e. exit #4, detector #2, etc).
N(I,5)	Time of incident start.
N(I,6)	Time of incident finish.
N(I,7)	Not used.
N(I,8)	Next downstream object/vehicle in front of object I.

B.2.4 Three dimensional arrays

JSPEED(I,J,K)	Sum of speeds recorded at detector J, in lane K. I=1: speeds from all vehicles. I=2: just car speeds.
JSUM(I,J,K)	Number of times detector J records data I, in lane K. I=1: speeds of all vehicles. I=2: volumes of all vehicles. I=3: speeds from just cars.
JTRUCKS(I,J,K)	Number of trucks passing detector I, in lane J. K=1: total number of vehicles. K=2: number of trucks. Recording only begins after time IJ1.
KTT(I,J,K)	I=1: sum of CAR travel times (sec) from ent. J, to exit K. I=2: number of cars recorded entering at J and exiting at K. I=3: sum of the square of the car travel times from J to K.

	I=4: sum of TRUCK travel times (sec) from ent. J, to exit K. I=5: # of trucks recorded entering at J and exiting at K. I=6: sum of the square of the truck travel times from J to K.
LA(I,J,K)	Sum of distances travelled by veh. passing det. J, in lane K. I=1: for all vehicles. I=2: just for cars, not trucks.
LB(I,J,K)	# of veh. passing det. J in lane K during det. interval. I=1: for all vehicles. I=2: just for cars, not trucks.

B.3 Simulation module program listing

```
C
C        *******************************
C        *    Simulator Module of      *
C        *          FREEVU             *
C        *          -------            *
C        *  FREEWAY EVALUATION WITH    *
C        *    VISUAL UNDERSTANDING     *
C        *                             *
C        *  Version 1.0  July, 1990    *
C        *      Bruce Hellinga         *
C        *******************************
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A10/ TCH(100,3)
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A12/ JVOL(20,8),JSPEED(2,20,8),JSUM(3,20,8)
      COMMON /A13/ JTRUCKS(20,8,2),KSP
      COMMON /A14/ KLD(20)
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
      COMMON /A19/ KTT(6,20,20),KTV(2500)
      COMMON /A21/MAN(10,100,8),JTME(6,100),MTOT(6,100),IVTC(100),MAXC
      COMMON /A25/ MENU(10)
C
      CHARACTER*60 GEONAME,PARNAME
C
      CALL MENUOPT(GEONAME,PARNAME)
C
      CALL READ(GEONAME,PARNAME)
C
C     Write desired volumes and percent trucks
C     to output file LNCHGS
C
      IF (MENU(3).EQ.0) GO TO 82
      WRITE (4,768)
      WRITE (4,765)
      WRITE (4,766)
      WRITE (4,767)
      WRITE (4,769)
   82 CONTINUE
   83 MO = MF
      IT = 0
      IU = 0
      ITIME = 0
      IM=0
   56 IM = IM + 1
C       -determine vehicle probs of occuring based on %truck for new
C        session.
      DO 91 I=1,60
      NP(I) = NP1(I) * (100-JPER(IM))/10
   91 CONTINUE
C
      DO 92 I=61,100
      NP(I) = NP1(I)*JPER(IM)/10
   92 CONTINUE
C
   15 IT = IT+1
      IS = IT*KI/10
      IF (IS.GT.IJ1) IU = IU+1
C
C     current time and time remaining to screen
C
      ITIME =ITIME + 1
      IF (ITIME.LT.5) GO TO 16
      ITIME = 0
      WRITE(*,200) IT,(KT-IT)
C
   16 IK = 1
      IL = 1
      CALL SETUP
      GO TO 25
   20 CALL ORDER(I,J)
   25 I=LX(1)
      J=LF(I)
      IF (J.LE.MF) GO TO 30
      CALL VEHICLES(I,J)
      GO TO 20
   30 IF (N(J,2).EQ.91) GO TO 35
      CALL FIXEDOBJ(I,J)
      GO TO 20
   35 IF (IU.LT.MT) GO TO 50
      CALL DTCR
      IU = 0
C
C     indicate the end of the current time interval in *.Sim File.
   50 IF (((IS-IJ1).GE.IMSIM(1)).AND.((IS-IJ1).LE.IMSIM(2)).AND.
     #     (MENU(2).EQ.1)) WRITE(6,199)
      IF ((IS-IJ1).LT.IMTIME(IM)) GO TO 15
      CALL WRITE
      CALL ZERO
      IF (IM.LT.IMTOT) GO TO 56
      STOP
C
  199 FORMAT (1X,'-9')
  200 FORMAT ('+      CURRENT TIME = ',I4,5X,'TIME REMAINING = ',I4)
  765 FORMAT (' VEH.  VEH.   TIME  LANE LANE  POSIT.  SPD  DSP  DES',
     #2X,'PREV  CURR  IR')
  766 FORMAT ('  #    TYPE         FROM  TO                SPD     ',
     #3X,'LEAD  FOLL')
  767 FORMAT ('              (sec)            (ft) (ft/s)(ft/s)')
  768 FORMAT (1X,'=============================================',
     #'===================')
  769 FORMAT (1X,'---------------------------------------------',
     #'-------------------')
C
      END
C
C
      SUBROUTINE MENUOPT(GEONAME,PARNAME)
C
      COMMON /A25/ MENU(10)
      CHARACTER*60 GEONAME,PARNAME
C
      OPEN (6,FILE='FILES')
      READ (6,*) GEONAME
      READ (6,*) PARNAME
      DO 20 I=1,6
        READ (6,*) J
        IF (J.GT.0) MENU(I) = 1
   20 CONTINUE
      CLOSE (6,FILE='FILES')
  500 RETURN
C
      END
C
C
      SUBROUTINE READ(GEONAME,PARNAME)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A10/ TCH(100,3)
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A14/ KLD(20)
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
      COMMON /A20/ NDIST(20,20)
      COMMON /A21/MAN(10,100,8),JTME(6,100),MTOT(6,100),IVTC(100),MAXC
      COMMON /A25/ MENU(10)
      COMMON /A26/ NN(75,2)
      COMMON /GRADES/ GRADE(8,100)
C
```

```
      CHARACTER*60 GEONAME,PARNAME,TEMPSTRG
      DIMENSION GRADELEN(20),INGRADE(8,20)
      INTEGER FROM,TOO
C
      DO 15 I=1,2500
      DO 14 J=1,8
        N(I,J)=0
   14   CONTINUE
   15 CONTINUE
C
C ==========================================================
C ===== OPEN FILES REQUIRED FOR VARIOUS OUTPUT           ===
C ==========================================================
C
C open file GEOMNAME.SIM for animation data; assigned as file 6
C
      IF (MENU(2).EQ.0) GO TO 18
      TEMPSTRG = GEONAME(1:(INDEX(GEONAME,'.')))//'SIM'
      OPEN (6,FILE=TEMPSTRG)
C - write name of geometry and vehicle file to simulation file
      WRITE(6,*) 'DATA.VEH'
      WRITE(6,*) GEONAME

C =====================================================================
C     Open file 9 for output of average volume, speed,
C     and density data.
C
   18 IF (MENU(1).EQ.1) OPEN (9,FILE='AVERAGES')
C
C     Open file 4 for output of data on lane changes
C
      IF((MENU(3).EQ.1).OR.(MENU(4).EQ.1)) OPEN (4,FILE='LNCHGS')
C
C     Open file 3 for output of total travel times.
C
      IF(MENU(5).EQ.1) OPEN (3,FILE='TIME')
C
C     Open file 5 for ouput of truck manoeuvre record.
C
      IF (MENU(6).EQ.1) OPEN (5,FILE='MANOEUVR')
C
C ==========================================================
C ===== READ IN SIMULATION CONTROL AND DEFAULT PARAMETERS ===
C ==========================================================
C
      OPEN (8,FILE=PARNAME)
C     set numcars to 0 to allow for complete simulation
      NUMCARS = 0
      READ (8,*) KT,IMTOT,IMSIM(1),IMSIM(2),JG
C     convert times from minutes to seconds
      KT =KT*60
      IMSIM(1) = IMSIM(1)*60
      IMSIM(2) = IMSIM(2)*60
      DO 93 I=1,IMTOT
```

```
        READ(8,*) JPER(I)
        READ(8,*) (LM(I,J),J=1,JG)
        READ(8,*) IMTIME(I)
        IMTIME(I)=IMTIME(I)*60
   93 CONTINUE
      READ(8,*) IJ1,MT
      KT=KT+IJ1
C ===================================================================
C       Read operational parameters.
C ===================================================================
      READ (8,*) KI,IN,IP,KA,KB,MD,KST(1),KST(2)
C       -read in restricted lane #
      READ (8,*) LRSTRCT
C
      CLOSE(8,FILE=PARNAME)
C
C ============================================================
C ===== READ IN GEOMETRY SPECIFICATIONS OF FREEWAY SYSTEM ===
C ============================================================
C
       OPEN (10,FILE=GEONAME)
C
       READ (10,*) ML,MF,JF,JG,ITL,MG,JM,JN
       ML = ML + 2
C      add 2 to number of lanes to account for dummy lanes
C      note also that incident information is not even read in
C
C       Read origins and destinations.
C
      DO 1 I=1,JG
        READ (10,*) (LS(I,J),J=1,JF)
        DO 3 J=1,JF
          IF (LS(I,J).LT.0) THEN
            LS(I,J)=0
          ENDIF
    3   CONTINUE
    1 CONTINUE
C ===================================================================
C       Read incidents.
C
C      IF (MI.EQ.0) GO TO 4
C      DO 2 I=1,MI
C        READ (10,*) (LI(I,J),J=1,10)
C    2 CONTINUE
C
C      Read object array.
C ===================================================================
    4 READ (10,*) (N(I,1),I=1,MF)
      DO 5 J=2,4
        READ (10,*) (N(I,J),I=1,MF)
    5 CONTINUE
      READ (10,*) (N(I,8),I=1,MF)
C
      READ (10,*) (LD(I),I=1,JM)
```

```
C        skip past lane section boundary loc data
      READ(10,*) (JUNK,I=1,JN)
C
      DO 7 I=3,ML
        READ (10,*) (LC(J,I),J=1,JM)
    7 CONTINUE
C ==================================================================
C     specify lane type for dummy lanes as 9=not a traffic lane
C ==================================================================
      DO 79 J = 1,2
        DO 78 I = 1,JM
          LC(I,J) = 9
   78   CONTINUE
   79 CONTINUE
C ==================================================================
C     read mandatory lane change matrix
C ==================================================================
      DO 8 I=3,ML
        READ (10,*) (LJ(J,I),J=1,JM)
        READ (10,*) (LK(J,I),J=1,JM)
    8 CONTINUE
C ==================================================================
C     read grades and transform into grades matrix
C ==================================================================
      READ(10,*) (GRADELEN(I),I=1,20)
      J1=0
      DO 81 I=1,20
        IF (GRADELEN(I).GT.0) J1=J1+1
   81 CONTINUE
      DO 82 I=1,ML-2
        READ(10,*) (INGRADE(I,J),J=1,20)
   82 CONTINUE
      DO 89 I=1,J1
        IF (I.EQ.1) THEN
          LOW=0
        ELSE
          LOW=GRADELEN(I-1)/500
        ENDIF
        JHI=GRADELEN(I)/500
        DO 80 K=LOW,JHI
          DO 70 L=1,ML-2
            GRADE(L,K)=INGRADE(L,I)
   70     CONTINUE
   80   CONTINUE
   89 CONTINUE
C       read past lane bound location data
      READ(10,*) (JUNK,I=1,20)
C ==================================================================
C     read in speed limits for each lane and each lane section
C ==================================================================
      DO 91 I =3,ML
        READ(10,*) (LSPEED(I,J),J=JN,1,-1)
   91 CONTINUE
C
```

```
      CLOSE(10,FILE=GEONAME)
C ===================================================================
C     Get first random number from internal computer clock.
C     All subsequent random numbers can now be generated using
C     the "RND" function.
C
      IRNU = RRAND()
C
C ===========================================================
C ===== READ IN VEHICLE CHARACTERISTICS                   ===
C ===========================================================
C
C     Read data from file DATA.VEH for vehicle characteristics.
C
      OPEN (8,FILE='DATA.VEH')
      READ (8,*) NUM,MAXC
      DO 10 I=1,NUM
        READ (8,*) I1,IVTC(I1),(TCH(I1,K),K=1,3),LN(I1),Z(I1),
     #             NP1(I1),NF(I1)
   10 CONTINUE
C
      CLOSE(8,FILE='DATA.VEH')
C ===================================================================
      IM=0
C
      DO 66 I=1,MF
      NN(I,1)=N(I,3)
      NN(I,2)=N(I,8)
   66 CONTINUE
C ===================================================================
C       derive the distance from each entrance to each possible exit
C       so that average travel times and speeds can be determined
C ===================================================================
      DO 73 J =1,JG
        DO 72 I =1,JF
          DO 71 K=1,MF
C             if type = system start or on ramp and ent # is current
            IF (((N(K,2).EQ.90).OR.(N(K,2).EQ.22)).AND.(N(K,4).EQ.J))
     #        FROM = N(K,1)
C               if obj is d/s end and its num is = current exit num
C               or its an off ramp end
            IF (((K.LE.ML).AND.(N(K,4).EQ.I)).OR.(N(K,2).EQ.11))
     #        TOO = N(K,1)
            IF (FROM.GT.TOO) THEN
              NDIST(J,I) = TOO-FROM
            ELSE
              NDIST(J,I) = 0
            ENDIF
   71     CONTINUE
   72   CONTINUE
   73 CONTINUE
C ===================================================================
C
   26 RETURN
```

```
C
      END
C
      SUBROUTINE WRITE
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A10/ TCH(100,3)
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A12/ JVOL(20,8),JSPEED(2,20,8),JSUM(3,20,8)
      COMMON /A13/ JTRUCKS(20,8,2),KSP
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A19/ KTT(6,20,20), KTV(2500)
      COMMON /A20/ NDIST(20,20)
      COMMON /A21/MAN(10,100,8),JTME(6,100),MTOT(6,100),IVTC(100),MAXC
      COMMON /A25/ MENU(10)
C
      DIMENSION IAVG(4,8),KPER(8),ITME(20),ISTD(20)
      DIMENSION LSUM(10)
C       -determine actual percent trucks generated
      K=0
      L=0
      DO 2 I=1,JG
        K = K + JGEN(2,I)
        L = L + JGEN(1,I)
    2 CONTINUE
      RPA = K*100.0/L
C     - determine time over which current data was recorded (sec)
      IF (IM.EQ.1) THEN
        JTIME=IS-IJ1
      ELSE
        JTIME=IS-IJ1-IMTIME(IM-1)
      ENDIF
C
C     Write average volume, speed, and density data
C     to file AVERAGES.OUT
C
   92 IF(MENU(1).EQ.0) GO TO 15
      IF (IM.GT.1) GO TO 73
      WRITE (9,768)
      WRITE (9,750)
   73 WRITE (9,768)
      DO 74 I=1,JG
      WRITE (9,756) I,LM(IM,I),(JGEN(1,I)*3600/JTIME)
   74 CONTINUE
      WRITE (9,769)
      WRITE (9,757) RPA
      WRITE (9,758) JTIME/60,IM
      WRITE (9,769)
      WRITE (9,770)
      WRITE (9,772) LRSTRCT
   15 DO 80 I=1,MG
      IF(MENU(1).EQ.0) GO TO 16
      WRITE (9,751) I
      WRITE (9,752) (J,J=1,ML-2)
   16 JTOTAL=0
      DO 75 J=1,ML-2
C
        IF(JSUM(2,I,J).LE.0) GO TO 72
        IAVG(1,J)=JVOL(I,J)/JSUM(2,I,J)
C
        JTOTAL=JTOTAL+IAVG(1,J)
C
        IF (JSUM(1,I,J).LE.0) GO TO 72
        IAVG(2,J)=JSPEED(1,I,J)/JSUM(1,I,J)
C
        IF (JSUM(3,I,J).LE.0) GO TO 72
        IAVG(4,J)=JSPEED(2,I,J)/JSUM(3,I,J)
        IF (IAVG(2,J).LE.0) GO TO 89
        IAVG(3,J)=IAVG(1,J)/IAVG(2,J)
        GO TO 75
C
   89   IAVG(2,J)=0
        GO TO 75
C
   72     IAVG(1,J)=0
        IAVG(2,J)=0
        IAVG(3,J)=0
C
   75   CONTINUE
C
C     Calculate the percent vehicles in each lane
      IF (JTOTAL.EQ.0) GO TO 77
      DO 76 J=1,ML-2
        KPER(J)=0
        KPER(J)=IAVG(1,J)*100/JTOTAL
   76   CONTINUE
        GO TO 78
C
   77   DO 79 J=1,ML-2
        KPER(J)=0
   79   CONTINUE
C
C       Write results to AVERAGES
C
   78       IF (MENU(1).EQ.0) GO TO 80
        WRITE (9,753) (IAVG(1,I1),I1=1,ML-2),JTOTAL
      WRITE (9,759) (KPER(I1),I1=1,ML-2)
        WRITE (9,754) (IAVG(2,I1),I1=1,ML-2)
        WRITE (9,755) (IAVG(3,I1),I1=1,ML-2)
        WRITE (9,760) (JTRUCKS(I,I1,2),I1=1,ML-2)
        WRITE (9,761) (JTRUCKS(I,I1,1),I1=1,ML-2)
   80 CONTINUE
```

```
      IF (MENU(1).NE.0) WRITE(9,768)
C
C     Write lane change attempts to data file LNCHGS
C
   17 IF (MENU(4).EQ.0) GO TO 18
      WRITE (4,768)
      DO 81 I=1,JG
      WRITE (4,756) I,LM(IM,I),(JGEN(1,I)*3600/JTIME)
   81 CONTINUE
      WRITE (4,769)
      WRITE (4,757) RPA
      WRITE (4,758) JTIME/60,IM
      WRITE (4,769)
      WRITE (4,770)
      WRITE (4,772) LRSTRCT
      WRITE (4,774)
C     WRITE (4,776) JCHANGE(8,1),JCHANGE(8,2)
C     only write amount of actual changes made not attempts or success
C
      WRITE (4,778) JCHANGE(1,3)
      WRITE (4,777) JCHANGE(2,3)
      WRITE (4,775) JCHANGE(3,3)
      WRITE (4,783) JCHANGE(9,3)
      WRITE (4,779) JCHANGE(4,3)
      WRITE (4,780) JCHANGE(5,3)
      WRITE (4,781) JCHANGE(6,3)
      WRITE (4,782) JCHANGE(7,3)
      JTT=0
      DO 280 I=1,9
      JTT=JTT+JCHANGE(I,3)
  280 CONTINUE
      JTTL=JCHANGE(1,3)+JCHANGE(4,3)+JCHANGE(6,3)
      JTTR=JCHANGE(2,3)+JCHANGE(3,3)+JCHANGE(9,3)+JCHANGE(5,3)
     #+JCHANGE(7,3)
      WRITE (4,769)
      WRITE (4,784) JTTL
      WRITE (4,785) JTTR
      WRITE (4,786) JTT
      WRITE (4,768)
C
C     Write total travel time data to file TIME
C
   18 IF (MENU(5).EQ.0) GO TO 20
      DO 86 K1=1,3
        WRITE(3,768)
        IF (K1.EQ.1) WRITE(3,790)
      IF (K1.EQ.2) WRITE(3,796)
        IF (K1.EQ.3) WRITE(3,797)
        WRITE(3,769)
        DO 85 K=1,4,3
          IF (K.EQ.1) WRITE(3,791)
          IF (K.GT.1) WRITE(3,795)
          WRITE(3,792)
          WRITE(3,793) (I,I=1,JF)
```

```
C
          DO 84 I=1,JG
            DO 83 J=1,JF
            IF (KTT(K+1,I,J).LE.0) GO TO 82
            ITME(J)=KTT(K,I,J)/KTT(K+1,I,J)
            IF (KTT(K+1,I,J).LE.1) GO TO 88
            ISTD1=KTT(K+2,I,J)-((KTT(K,I,J)**2)/KTT(K+1,I,J))
            ISTD(J)=(ISTD1/(KTT(K+1,I,J)-1))**(0.5)
              GO TO 83
   82         ITME(J)=0
   88         ISTD(J)=0
C
   83       CONTINUE
C
            IF (K1.EQ.1) WRITE(3,794) I,(ITME(J),J=1,JF)
          IF (K1.EQ.2) WRITE(3,794) I,(ISTD(J),J=1,JF)
            IF (K1.EQ.3) WRITE(3,794) I,(KTT(K+1,I,J),J=1,JF)
   84     CONTINUE
          IF (K.EQ.1) WRITE(3,701)
   85   CONTINUE
   86 CONTINUE
      WRITE(3,768)
C
C     Write record of vehicle manoeuvres to file MANOEUVR
C
   20 IF (MENU(6).EQ.0) GO TO 25
      WRITE (5,768)
      DO 100 I=1,JG
      WRITE (5,756) I,LM(IM,I),(JGEN(1,I)*3600/JTIME)
  100 CONTINUE
      WRITE(5,757) RPA
      WRITE(5,768)
      WRITE (4,770)
      WRITE (4,772) LRSTRCT
      WRITE(5,810)
      WRITE(5,769)
      DO 110 I=1,MAXC
        DO 104 J=1,10
          LSUM(J)=0
  104   CONTINUE
        LOCN=(LD(1)/200)+1
        DO 109 J=1,8
          DO 108 K=1,LOCN
          LSUM(J)=LSUM(J)+MAN(I,K,J)
  108     CONTINUE
  109   CONTINUE
        DO 112 J=1,8
          LSUM(J) = IFIX(LSUM(J)/3)
  112   CONTINUE
        WRITE(5,809) I,LSUM(1),LSUM(2),LSUM(3),LSUM(4),LSUM(5),
     #                 LSUM(6),LSUM(7)
  110 CONTINUE
      WRITE(5,768)
C
```

```
   25 RETURN
C
C     Format statements for output to files.
C
  701 FORMAT (/)
  751 FORMAT (/,15X,' DETECTOR #',I2,/)
  750 FORMAT (10X,'AVERAGE VOLUME, SPEED AND DENSITY VALUES')
  752 FORMAT (10X,'LANE NUMBER',7X,8I5)
  753 FORMAT (10X,'VOLUME   (vph)',5X,9I5)
  754 FORMAT (10X,'SPEED    (km/h)',4X,8I5)
  755 FORMAT (10X,'DENSITY  (v/km)',4X,8I5)
  756 FORMAT (5X,'ENTR # ',I1,2X,'SPEC. VOL  = ',I5,6X,
     #'GENERATED VOLUME = ',I4,' (vph)')
  757 FORMAT (5X,'PERCENT TRUCKS PRODUCED   = ',F4.1,'%')
  758 FORMAT (5X,'MONITORED SIMULATION TIME = ',I5,' (MIN)',
     #': SESSION = ',I3)
  759 FORMAT (10X,'PERCENT IN LANE',4X,8I5)
  760 FORMAT (10X,'# OF TRUCKS ',7X,8I5)
  761 FORMAT (10X,'# OF VEHICLES',6X,8I5)
  768 FORMAT (1X,'==================================================',
     #'==================')
  769 FORMAT (1X,'--------------------------------------------------',
     #'------------------')
  770 FORMAT (10X,'LANE # 1 CORRESPONDS TO THE MEDIAN LANE:')
  772 FORMAT (10X,'LANE # ',I1,' IS A TRUCK RESTRICTED LANE')
  774 FORMAT (28X,'       ',8X,'       ',5X,'ACTUAL',/)
  775 FORMAT (5X,'MAX ACCEL <0-> YIELD',4X,5X,10X,5X,10X,I4)
  777 FORMAT (5X,'PASS ON RIGHT ',10X,5X,10X,5X,10X,I4)
  778 FORMAT (5X,'PASS ON LEFT  ',10X,5X,10X,5X,10X,I4)
  779 FORMAT (5X,'MANDATORY LEFT',10X,5X,10X,'    ',10X,I4)
  780 FORMAT (5X,'MANDATORY RIGHT',9X,5X,10X,'    ',10X,I4)
  781 FORMAT (5X,'DESIRED LEFT  ',10X,5X,10X,'    ',10X,I4)
  782 FORMAT (5X,'DESIRED RIGHT ',10X,5X,10X,'    ',10X,I4)
  783 FORMAT (5X,'SLOW W/ CAR BEHND-YLD',3X,5X,10X,5X,10X,I4)
  784 FORMAT (5X,'TOTAL TO LEFT ',39X,I5)
  785 FORMAT (5X,'TOTAL TO RIGHT',39X,I5)
  786 FORMAT (5X,'TOTAL LANE CHANGES',35X,I5)
  790 FORMAT (10X,'AVERAGE TOTAL TRAVEL TIMES (seconds)')
  791 FORMAT (5X,'CARS:',/)
  792 FORMAT (5X,' ENTRANCE',11X,'EXIT LOCATION #')
  793 FORMAT (14X,20I7)
  794 FORMAT (10X,I2,3X,20I7)
  795 FORMAT (5X,'TRUCKS:',/)
  796 FORMAT (10X,'STANDARD DEVIATION OF TRAVEL TIMES')
  797 FORMAT (10X,'TOTAL NUMBER OF OBSERVATIONS')
  809 FORMAT(5X,I6,3X,7I6)
  810 FORMAT(5X,'VEH CLASS',5X,'1',5X,'2',5X,'3',5X,'4',5X,'5',5X,
     #'6',5X,'7')
      END
C
      SUBROUTINE ZERO
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A10/ TCH(100,3)
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A12/ JVOL(20,8),JSPEED(2,20,8),JSUM(3,20,8)
      COMMON /A13/ JTRUCKS(20,8,2),KSP
      COMMON /A14/ KLD(20)
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A19/ KTT(6,20,20),KTV(2500)
      COMMON /A21/MAN(10,100,8),JTME(6,100),MTOT(6,100),IVTC(100),MAXC
      COMMON /A22/ NN1(2500)
      COMMON /A26/ NN(75,2)
C
C     ZERO ALL ARRAYS INVOLVED WITH RECORDING OUTPUT DATA
C
C       -zero arrays that sum number of vehicles generated
c        and keep track of total number of vehicles passing dtcrs
C
      DO 20 I=1,20
        JGEN(1,I)=0
        JGEN(2,I)=0
        DO 18 J=1,8
          JTRUCKS(I,J,1)=0
          JTRUCKS(I,J,2)=0
   18   CONTINUE
   20 CONTINUE
C
C     -zero manoeuvre accumulating arrays
C
      DO 124 I=1,9
      JCHANGE(I,1)=0
      JCHANGE(I,2)=0
      JCHANGE(I,3)=0
  124 CONTINUE
C
C      -reset dtcr recording arrays
C
      DO 129 I=1,MG
      DO 127 J=1,ML-2
        JSPEED(1,I,J)=0
        JSPEED(2,I,J)=0
        JVOL(I,J)=0
        JSUM(1,I,J)=0
        JSUM(2,I,J)=0
        JSUM(3,I,J)=0
  127   CONTINUE
  129 CONTINUE
C
C     -reset buffer containing next vehicle to be placed
C
      DO 131 I=3,JG
      DO 130 J=1,3
        IGEN(I,J)=0
  130   CONTINUE
  131 CONTINUE
C
C     -reset array counting travel times
C
      DO 140 I=1,6
        DO 139 J=1,20
          DO 138 K=1,20
          KTT(I,J,K)=0
  138   CONTINUE
  139 CONTINUE
  140 CONTINUE
C
      DO 150 I=1,MAXC
      DO 149 J=1,100
        JTME(I,J)=0
        MTOT(I,J)=0
        DO 148 K=1,8
          MAN(I,J,K)=0
  148     CONTINUE
  149 CONTINUE
  150 CONTINUE
C
      RETURN
      END
C
C
      SUBROUTINE ORDER(I,J)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
C
      LX(1)=I
      J=LF(I)
      DO 1 JJ=2,ML
        IJ=LX(JJ)
        JK=LF(IJ)
        IF (N(J,1).GE.N(JK,1)) GO TO 2
        LX(JJ-1)=IJ
        LX(JJ)=I
    1 CONTINUE
    2 RETURN
      END
C
      SUBROUTINE SETUP
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
C
      DO 1 J=1,ML
        LL(J)=J
        LF(J)=N(J,3)
        LX(J)=J
        IF (J.EQ.1) GO TO 1
        J1=J
        J3=LF(J1)
        DO 2 J2=1,J1-1
          J4=LX(J1-J2)
              J5=LF(J4)
          IF (N(J3,1).LE.N(J5,1)) GO TO 2
              LX(J1-J2+1)=LX(J1-J2)
              LX(J1-J2)=J1
    2   CONTINUE
    1 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE DTCR
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A10/ TCH(100,3)
      COMMON /A12/ JVOL(20,8),JSPEED(2,20,8),JSUM(3,20,8)
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A25/ MENU(10)
      DIMENSION LU(10),LV(10),LU2(10)
C
C     indicate that dtcr info follows by placing a -100 in position
C     column
      IF (((IS-IJ1).GT.IMSIM(1)).AND.((IS-IJ1).LE.IMSIM(2)).AND.
     #    (MENU(2).GT.0)) WRITE(6,12)
   12 FORMAT (1X,'-100')
      DO 25 I1=1,MG
        DO 15 I2=1,ML-2
          LU(I2)=0
          LV(I2)=LB(1,I1,I2)*3600/MT
C           Metric Version
C        Speed - km/h, Density - veh/km
C
        IF ((LA(1,I1,I2).EQ.0).AND.(LB(1,I1,I2).EQ.0)) GO TO 10
        IF ((LA(2,I1,I2).EQ.0).AND.(LB(2,I1,I2).EQ.0)) GO TO 10
          LU(I2)=(LB(1,I1,I2)*30000/(44*LA(1,I1,I2)))*16/10
          LU2(I2)=(LB(2,I1,I2)*30000/(44*LA(2,I1,I2)))*16/10
        IF ((LU(I2).LE.0).OR.(LU2(I2).LE.0)) GO TO 10
        GO TO 13
C
   10     LU(I2)=0
          LU2(I2)=0
   13   I4 = LU(I2)/2
C
C           Eliminate data produced before freeway fills up.
C
        IF (I4.EQ.0) GO TO 11
          IF (IS.LT.IJ1) GO TO 5
C
C         Keep track of volumes, speeds, and densities,
C         so that average volume for each detector in each
C         lane can be calculated.
C
        JSPEED(1,I1,I2)=JSPEED(1,I1,I2)+LU(I2)
        JSUM(1,I1,I2)=JSUM(1,I1,I2)+1
        IF(LU2(I2).EQ.0) GO TO 11
        JSPEED(2,I1,I2)=JSPEED(2,I1,I2)+LU2(I2)
        JSUM(3,I1,I2)=JSUM(3,I1,I2)+1
C
   11   JVOL(I1,I2)=JVOL(I1,I2)+LV(I2)
          JSUM(2,I1,I2)=JSUM(2,I1,I2)+1
C
    5     LA(1,I1,I2)=0
        LA(2,I1,I2)=0
          LB(1,I1,I2)=0
        LB(2,I1,I2)=0
   15   CONTINUE
      IF (MENU(2).EQ.0) GO TO 25
C     write speed and density to simulation file in imperial units in
C     order to be consistant with rest of file. SPEED = MPH;D=v/mi
        IF (((IS-IJ1).GT.IMSIM(1)).AND.((IS-IJ1).LE.IMSIM(2)))
     #    WRITE (6,42) I1,(I3,LV(I3),LU(I3)*10/16,I3=1,ML-2)
   25 CONTINUE
C
      RETURN
C
   42 FORMAT (1X,I2,10(I2,I5,I4))
      END
C
C
      SUBROUTINE ACCLEAD(IY,JJ,KTA,KD)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
C
      KY=N(JJ,2)
      KTB=KTA
      MV=N(JJ,8)
      KC=MD
      KD=N(JJ,5)*10+NJ(KY)
      IF (N(JJ,7).LT.LJ(IK,IY).OR.N(JJ,7).GT.LK(IK,IY)) GO TO 1
      IF (MV.GT.MF) GO TO 10
      GO TO 12
    1 IF (MV.LE.MF) GO TO 10
      IF (N(MV,1).LE.LD(IK)) GO TO 10
      MV=1
   10 CALL EMRGNCY(IY,MV,JJ,KTA,KTB,KC,KDD)
      IF (KD.GT.KDD) KD=KDD
      IF (KD.LT.MD) KD=MD
   12 IF (KD.GT.0) KD=0
      RETURN
      END
C
C
      SUBROUTINE EMRGNCY(IY,MV,JJ,KTA,KTB,KC,KD)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
C
      LAG=KB
      KD=0
      IF (N(JJ,5).LT.3) LAG=0
      KET=KTB-LAG
      SK=SA(JJ)
      KXB=N(JJ,1)
      IF (MV.GT.MF) GO TO 1
      SJ=0
      KXA=LD(IK)
      IF (KXA.LE.KXB) GO TO 45
      KDVA=0
      KN=0
      GOTO 3
    1 KY=N(MV,2)
      SJ=SA(MV)
      KXA=N(MV,1)
      KDVA=INT(LSPEED(IY,IL)*SMC*(1+ZB*Z(KY)))
      KN=LN(KY)
    3 KL=SJ+KC*KTA/100
      IF (KL.LT.0) KL=0
      IF (KL.GT.KDVA) KL=KDVA
C       don't know if KTM can be negative so if KL < SJ set KL=SJ
      IF (KL.LT.SJ) KL=INT(SJ)
      IF (KC.EQ.0) GO TO 5
      KTM=100*(KL-SJ)/KC
      GO TO 15
    5 KTM=KTA
C
C     Determine KD.
C
   15 KXA1=KXA+SJ*KTM/10+KC*KTM*KTM/2/1000+KL*(KTA-KTM)/10
      KB1=2*10*SK/KET-MD/10-2*MD*LAG/KET/10
      KC1=(KXA1-KXB-SK*KTB/10-KN-LAG*SK/10)*(2*10*MD/KET/KET)
     #    +100*(SK*SK-KL*KL)/KET/KET
      KBB=KB1*KB1-4*KC1
      IF (KBB.LT.0) GO TO 25
      BB=KBB
      KD=10*(-KB1+SQRT(BB))/2
      CC=KL**2+((MD*LAG)**2)/1000
      IF (KD.GE.(100*SQRT(CC)+MD*LAG-100*SK)/KET) GO TO 45
      KD=2*1000*(KXA1-KXB-SK*KTB/10-KN)/KET/KET
      IF (KD.GT.-100*SK/KET) GO TO 45
      IF (KXA1-KXB-KN.LE.0) GO TO 25
      KD=-10*SK*SK/(2*(KXA1-KXB-KN))
      GO TO 45
   25 KD=MD-10
   45 RETURN
      END
C
C
C
      SUBROUTINE FMOVE(MV,MX,IY)
C
C     Move vehicle ahead on the freeway.
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON/A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
C
      MZ = N(MX,6)
      KY=N(MX,2)
      SP=SA(MX)
C
      IV2=SP*1.09728
      IV1=((IV2-10)/15)+1
      IF (IV1.GT.7) IV1=7
C
      KD=MD
      KAC = N(MX,5)*10
      KACC = KAC + NJ(KY)
      CALL REQUIRED(IY,MX,KDS,KO)
      IF (MV.LT.MF) GO TO 2
      MY = N(MV,6)
      IF (MY.NE.0) GO TO 20
    2 IF (MZ.NE.0) GO TO 30
C
C     Check incident effects.
C
      IC = LL(2)
      IF (N(IC,2).NE.60) GO TO 5
      IF (IT.LT.N(IC,5).OR.IT.GT.N(IC,6)) GO TO 5
      IF (LI(IC,IY).EQ.100) GO TO 50
      KF = 1000*NF(KY)/(100-LI(IC,IY))
      GO TO 10
    5 KF = 10*NF(KY)
C
C     Car following model to determine acceleration or deceleration.
C
   10 JCO=KF
      IF (MV.LE.MF) GO TO 45
      VD=SA(MV)-SA(MX)
      IF (VD.GT.10) JCO=0
      KYA=N(MV,2)
      KACC = 2*(1000*(N(MV,1)-N(MX,1)-LN(KYA)-10-(10*KI+KF)*
     #SA(MX)/100)-JCO*(VD)**2)/(KI*KI+2*KF*KI/10)
      IF (KACC.LT.MDC(IV1)) KACC=MDC(IV1)
C
   15 KTA = 0
      KTB = KI
      GO TO 40
C
   20 IF (MZ.NE.0) GO TO 30
   25 KTA=(IN-IABS(MY))*KI
      KTB=KTA+KI
      GO TO 35
   30 KTB=(IN-IABS(MZ))*KI
      KTA=KTB-KI
      IF (N(MX,6).GT.0) N(MX,6) = N(MX,6) + 1
      IF (N(MX,6).LT.0) N(MX,6) = N(MX,6) - 1
      IF (MV.LE.MF) GO TO 60
      IF (KTA.EQ.0) GO TO 40
   35 CALL ACCLEAD(IY,MV,KTA,KD)
   40 CALL EMRGNCY(IY,MV,MX,KTA,KTB,KD,KACCL)
      IF (KACC.GT.KACCL) KACC=KACCL
   45 IF (KO.EQ.0) GO TO 60
   50 KTA=0
      KTB=KI
      CALL EMRGNCY(IY,1,MX,KTA,KTB,0,KACCL)
C - if a vehicle is stopped in front of a fixed obj waiting to
C   make a lane change, then don't let it accelerate past obj
C   unless it has changed lanes.
C     if emrgency decel is positive but veh is close to end of sect
C     reset accel to zero.
      IF ((KACCL.GT.0).AND.(N(MV,1)-N(MX,1).LE.4)) KACCL = 0
      IF (KACC.GT.KACCL) KACC=KACCL
   60 CALL MOVIT(MX,IY,KACC)
      RETURN
      END
C
C
      SUBROUTINE ACCEL(MX,SP,IY,IGD,AC)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A10/ TCH(100,3)
      COMMON /GRADES/ GRADE(8,100)
C
      KY=N(MX,2)
C
      IF (IGD.EQ.10) GO TO 21
      IGRAD=IGD
      GO TO 55
C
C     Determine grade of current physical section
```

```
C
   21 IGRAD = GRADE(IY-2,N(MX,1)/500)
C
C  21 ITEMP = LL(2)
C   2 IF (N(ITEMP,1).GT.N(MX,1)) GO TO 3
C     IF (N(ITEMP,2).EQ.80) GO TO 4
C     IF ((N(ITEMP,2).LT.91).OR.(N(ITEMP,2).GT.91)) GO TO 3
C     IGRAD = 0
C     GO TO 55
C   3 ITEMP = N(ITEMP,3)
C     GO TO 2
C   4 IGRAD = N(ITEMP,6)
C
C     Calc. max. avail. acceleration based on equations
C     of motion.
C
   55 G=TCH(KY,2)*9.81/1000
      SP1=SP*1.09728
      IF(SP1.LE.0) SP1=0.01
      TE=2175*TCH(KY,1)/SP1
      RR=(7.6+0.056*SP1)*G
C       -air resistance coefficient =0.0011 for cars
      IF (MX.LT.60) THEN
        RA=0.0011*SP1*SP1*TCH(KY,3)
      ELSE
        RA=0.037*SP1*SP1*TCH(KY,3)
      ENDIF
      RG=10*G*IGRAD
      TR=RR+RA+RG
      AC1=(TE-TR)/TCH(KY,2)
C     units of accel are 10*ft/s^2
      AC=AC1*3.281*10
      IF (AC.GT.500.0) AC=500.0
C      -limit size of ac to prevent integer overflows
   99 RETURN
      END
C
C
      SUBROUTINE MOVIT(MX,IY,KACC)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A10/ TCH(100,3)
      COMMON /A13/ JTRUCKS(20,8,2),KSP
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
      COMMON /A19/ KTT(6,20,20),KTV(2500)
      COMMON /A20/ NDIST(20,20)
      COMMON /A21/MAN(10,100,8),JTME(6,100),MTOT(6,100),IVTC(100),MAXC
      COMMON /A22/ NN1(2500)
      COMMON /A25/ MENU(10)
C
      KY=N(MX,2)
      KXBB=N(MX,1)
      LAG=0
      IDS=INT(LSPEED(IY,IL)*SMC*(1+ZB*Z(KY)))
      SP=SA(MX)
      CALL ACCEL(MX,SP,IY,10,AC)
C
      IV2=SP*1.09728
      IV1=((IV2-10)/15)+1
      IF (IV1.GT.7) IV1=7
C
      ACC=KACC
      IF (ACC.GT.AC) ACC=AC
      IF (ACC.GT.MAC(IV1)) ACC=MAC(IV1)
      IF (N(MX,5).GT.-4) LAG=KB
      IF (ACC.GT.0) LAG = KA
      IF (ACC.GT.30) LAG=0
c
C     for a forced decel i.e. on steep grade, no driver
C     reaction is involved therefore lag=0
C
      IF ((ACC.EQ.AC).AND.(AC.LT.0)) LAG=0
C =================================================================
C       if current speed is greater than desired speed
C       based on the current speed limit, then decelerate
C       at 60% of the "normal" deceleration rate.
C =================================================================
      IF (SP.GT.IDS) THEN
        IF (ACC.GT.(0.6*MDC(IV1))) ACC = 0.6*MDC(IV1)
      ENDIF
C =================================================================
C     Update vehicle
C =================================================================
    6 KET = KI-LAG
      KES = KET*10
      VB = SA(MX)*10 + ACC*KES/100
C      IF (VB.GT.IDS*10) VB = IDS*10
      IF (VB .LT. 0) VB = 0
      KXB=(VB+SA(MX)*10)*KES/100/2+N(MX,1)*10+ LAG*SA(MX)
      IF (ACC.EQ.0) GO TO 15
      AKU = 100*(VB-SA(MX)*10)/ACC
      KXB=(VB**2-(10*SA(MX))**2)/(2*ACC)+N(MX,1)*10+VB*(KES-AKU)/100
     # + LAG*SA(MX)
      IF ((KES-AKU).LE. 2) GO TO 15
      ACC = 0
   15 KXP1=N(MX,1)
C =================================================================
C       prevent a vehicle from passing a lane drop obj= #4
C =================================================================
      MV = LL(IY)
      IF ((N(MV,2).EQ.4).AND.(KXB/10.GE.N(MV,1))) THEN
        N(MX,1) = N(MV,1) - 1
      ELSE
        N(MX,1)=KXB/10
      ENDIF
C
      SA(MX)=VB/10
      IF (SA(MX).LT.0.01) SA(MX)=0.00
      N(MX,5)=ACC/10
      KACC=IFIX(ACC)
C
      MV=LL(IY)
C       determine the dtcr # in lane 1 d/s of vehicle (JQ)
      JP=LL(1)
      JQ=N(JP,4)
      LL(IY) = MX
      LF(IY) = N(MX,3)
C ===================================================================
C     record vehicle manoeuvres
C ===================================================================
      IF (MENU(6).EQ.0) GO TO 10
      IF ((IS.LT.IJ1).OR.(N(MX,1).LT.KST(1)).OR.(N(MX,1).GT.KST(2)))
    # GO TO 10
      MNT=8
      IF (KACC.LT.MDC(IV1)) MNT=7
      IF (NN1(MX).GT.0) MNT=NN1(MX)
      LOC=(N(MX,1)/200)+1
      ITM=(KI/10)
      ITYP = IVTC(KY)
      MAN(ITYP,LOC,MNT)=MAN(ITYP,LOC,MNT)+ITM
      JTME(ITYP,LOC)=JTME(ITYP,LOC)+ITM
      I=(KXP1/200)+1
      IF(LOC.GT.I) MTOT(ITYP,LOC)=MTOT(ITYP,LOC)+1
      IF((LOC.GT.I).AND.(I.EQ.1)) MTOT(ITYP,I)=MTOT(ITYP,I)+1
C ===================================================================
C  Write stuff to filename.SIM
C  Vehicle parameters are now written to file according to
C  vehicle position, from d/s to u/s across all lanes, not on a
C  lane basis.  As well, only the following values are written:
C  old Position, new pos , Lane, Vehicle Type, & Lane change flag.
C
C  Only write the data to the file if currently within time period
C  specified by IMSIM(1) start time and end time IMSIM(2) and
C  user desires file to be created.

   10 IF (((IS-IJ1).GE.IMSIM(1)).AND.((IS-IJ1).LE.IMSIM(2)).AND.
     #    (MENU(2).EQ.1)) then
        WRITE (6,911) N(MX,1),KXP1,IY-2,KY,N(MX,6)
      endif
  911 FORMAT (1X,2I6,I2,2I3)

      IF (N(MX,6).EQ.IN) N(MX,6)=0
      IF (N(MX,6).EQ.-IN) N(MX,6)=0
      IF (N(MX,6).EQ.0) NN1(MX)=0
      IF (MV.GT.MF) GO TO 20
      IF (N(MX,1).LE.N(MV,1)) GO TO 20
      LL(IY)=MV
      MV1=N(MX,3)
      N(MV,3)=MV1
      N(MV1,8)=MV
      N(MX,1)=0
C ====================================================================
C     Since the current vehicle has exited the system keep
C     track of the time taken to travel from entrance k to exit k1
C ====================================================================
   21 IF (IS.LT.IJ1) GO TO 25
      IJ2=1
      IF (N(MX,2).GT.60) IJ2=4
C     K = entrance number MX entered by.
      K=N(MX,4)
C     K1 = exit number,
      K1=N(MV,4)
      IF (K1.LE.0) GO TO 25
C ====================================================================
C     add time to running total
C ====================================================================
      K2=IS-KTV(MX)
      KTT(IJ2,K,K1)=KTT(IJ2,K,K1)+K2
      IJ2=IJ2+1
C     add 1 to vehicle sum
      KTT(IJ2,K,K1)=KTT(IJ2,K,K1)+1
C     add square of time to sum of x^2
      IJ2=IJ2+1
      KTT(IJ2,K,K1)=KTT(IJ2,K,K1)+(K2*K2)
C ====================================================================
C     Keep track of the number and speed of vehicles passing
C     detector locations but do not start counting until
C     dtcr's begin monitoring.
C ====================================================================
   20 IF (IS.LT.IJ1) GO TO 25
      IF (N(JP,2).NE.50) GO TO 25
      IF (N(MX,1).LT.N(JP,1)) GO TO 25
      LB(1,JQ,IY-2) = LB(1,JQ,IY-2) + 1
      KXXB = N(MX,1)-KXBB
      IF (KXXB.LT.1) KXXB=1
      LA(1,JQ,IY-2) = LA(1,JQ,IY-2) + 100*KI/KXXB
C     Keep track of just car speeds and volumes
      IF(KY.GT.60) GO TO 24
      LA(2,JQ,IY-2) = LA(2,JQ,IY-2) + 100*KI/KXXB
      LB(2,JQ,IY-2) = LB(2,JQ,IY-2) + 1
C ====================================================================
C     Keep track of the number of trucks in each lane
C     as well as the total number of vehicles passing each dtcr
C ====================================================================
   24 JTRUCKS(JQ,IY-2,1)=JTRUCKS(JQ,IY-2,1)+1
      IF(N(MX,2).LE.60) GO TO 25
      JTRUCKS(JQ,IY-2,2)=JTRUCKS(JQ,IY-2,2)+1
   25 RETURN
```

```
      END
C
C
      SUBROUTINE CHECK(MV,MX,IY,ID,KO,IR,IH)
C
C     Check if a lane change is possible.
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
      COMMON /A22/ NN1(2500)
      COMMON /A25/ MENU(10)
C
      KXR=0
      SP=SA(MX)
      MJ=N(MX,3)
      KTB = IN*KI
      KTA = KTB - KI
      KACCL = 0
      KX = N(MX,1)
      IF (KO.EQ.0) GO TO 1
C     determine total distance over which lane change could be made.
C     if dist > 1500 ft then set equal to 1500 ft as this is dist
C     at which driver begins to react to mandatory changes.
      IF (IK.EQ.1) THEN
        KS = LD(IK)
      ELSE
        KS = LD(IK)-LD(IK-1)
      ENDIF
      IF (KS.GT.1500) KS=1500
C     note dist = length of current physical section implying that
C     lane change can occur only in current physical section.
C     urgency reflected by remaining distance if < 1500 ft.
      KXR=(KO-KX)*100/KS
      IF (KXR.GT.100) KXR=100
      IF (KXR.EQ.0) KXR=1
    1 KY = N(MX,2)
      MP = LL(ID)
      MR = LF(ID)
      IF (MP.LE.MF) GO TO 5
      CALL ACCLEAD(ID,MP,KTA,KD)
      CALL EMRGNCY(IY,MP,MX,KTA,KTB,KD,KACCL)
C
C     Take into account the remaining distance available, over
C     which the vehicle can make a lane change.
C
      CALL RISK(0,MINF,MX,KXR)
      IF (KACCL.LT.MINF) GO TO 20
    5 CALL REQUIRED(ID,MX,KDS,KO1)
      IF (KO1.EQ.0) GO TO 15
      CALL EMRGNCY(IY,MP,MX,KTA,KTB,KACCL,KACCN)
      IF (KACCL.GT.KACCN) KACCL=KACCN
C
      IV2=SP*1.09728
      IV1=((IV2-10)/15)+1
      IF (IV1.GT.7) IV1=7
C
      IF (KACCL.LT.MDC(IV1)) GO TO 20
   15 IF (MR.LE.MF) GO TO 25
      KTA = IN*KI
      KTB = KTA
      CALL EMRGNCY(IY,MX,MR,KTA,KTB,KACCL,KACCN)
      CALL RISK(1,MINF,MR,KXR)
      IF (KACCN.GE.MINF) GO TO 25
   20 IF (KO.EQ.0) GO TO 30
      IF (SA(MX).GT.3) GO TO 30
      IF (MP.LE.MF) GO TO 21
      IF (SA(MP).GT.3) GO TO 30
   21 IF (MR.LE.MF) GO TO 22
      IF (SA(MR).GT.3) GO TO 30
   22 KACCL=0
   25 N(MV,3)=MJ
      N(MJ,8)=MV
      N(MP,3)=MX
      N(MX,8)=MP
      N(MX,3)=MR
      N(MR,8)=MX
      IF(ID.GT.IY) N(MX,6)=1
      IF(ID.LT.IY) N(MX,6)=-1
      LF(IY)=MJ
      NN1(MX)=IR
      CALL MOVIT(MX,ID,KACCL)
   36 IH = 1
      GO TO 35
   30 IH=0
      NN1(MX)=0
C
C     Write data concerning lane changes to file #4
C
   35 IF ((MENU(3).EQ.0).AND.(MENU(4).EQ.0)) GO TO 40
      IF ((IH.EQ.0).OR.(IS.LT.IJ1)) GO TO 40
      IF ((N(MX,1).LT.KST(1)).OR.(N(MX,1).GT.KST(2))) GO TO 40
C
C     Count lane changes and record reason.
C
      IF (ID.EQ.IY) GO TO 40
      IF (ID.GT.IY) GO TO 38
C
      IF (IR.EQ.1) JCHANGE(1,3)=JCHANGE(1,3)+1
      IF (IR.EQ.4) JCHANGE(6,3)=JCHANGE(6,3)+1
      IF (IR.EQ.5) JCHANGE(4,3)=JCHANGE(4,3)+1
      GO TO 39
   38 IF (IR.EQ.2) JCHANGE(2,3)=JCHANGE(2,3)+1
      IF (IR.EQ.3) JCHANGE(3,3)=JCHANGE(3,3)+1
      IF (IR.EQ.4) JCHANGE(7,3)=JCHANGE(7,3)+1
      IF (IR.EQ.5) JCHANGE(5,3)=JCHANGE(5,3)+1
      IF (IR.EQ.6) JCHANGE(9,3)=JCHANGE(9,3)+1
C
C     Record situational parameters for each lane change made.
C     Data written to LNCHGS only if desired.
C
      JTEMPS = INT(LSPEED(IY,IL)*SMC*(1+ZB*Z(KY)))
   39 IF ((IH.EQ.0).OR.(MENU(3).EQ.0)) GO TO 40
      WRITE (4,100) MX,KY,IS,(IY-2),(ID-2),KX,SA(MX),JTEMPS,
     #N(MX,7),MV,MR,IR
   40 RETURN
  100 FORMAT (I4,3X,I3,3X,I5,3X,I2,3X,I2,3X,I5,2X,F5.1,1X,I3,3X,I1,
     #2X,I4,2X,I4,4X,I1)
      END
C
C
C
      SUBROUTINE RISK(JT,MK,MX,KE)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON/A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
C
C     Determine the maximum acceleration a specified vehicle
C     is willing to apply dependent on the remaining available
C     distance over which it is possible to make a lane change.
C     JT = (0,1) check gap location (in front, behind)
C     MK = MAX. deceleration MX is willing to undergo.
C
      MK=0
      SP=SA(MX)
      IV2=SP*1.09728
      IV1=((IV2-10)/15)+1
      IF (IV1.GT.7) IV1=7
C
      IF (KE.EQ.0) GO TO 15
      IF (KE.EQ.100) GO TO 15
      IF (JT.EQ.1) GO TO 3
      MK=MDC(IV1)*(100-KE)/100
      GO TO 15
C
C     if gap is behind MX, check if vehicle will be courteous and
C     allow MX to make the lane change
C
    3 CALL RANDOM(IRNU)
      IE=0
      IF (IRNU.LT.IP) IE=1
      IF (IE.EQ.0) GO TO 15
      MK=(MDC(IV1)*(100-KE))/100
   15 RETURN
      END
C
C
      SUBROUTINE GENERATE(IY,JJ,KK)
C
C     Generate freeway vehicles.
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A14/ KLD(20)
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
      COMMON /A19/ KTT(6,20,20),KTV(2500)
      REAL T,C,TBAR,H
C
      IF ((NUMCARS.NE.0).AND.(MO.GE.(MF+NUMCARS))) GO TO 45
C
    3 IY1=N(JJ,8)
C
      IF (IGEN(KK,1).EQ.0) GO TO 7
C -if leading obj is not a veh est. dist from time last veh generated.
      IF (IY1.GT.MF) GO TO 2
      IY2=KLD(KK)
      IF (IY2.LE.0) GO TO 11
C - estimate dist based on speed of 90 ft/sect
      IDIST=(IS-KLD(KK))*90
      IF (IDIST.LE.IGEN(KK,3)) GO TO 45
C ================================================================
C     For NO vehicle existing in current lane.
C ================================================================
   11 M = IGEN(KK,1)
      I1 = IGEN(KK,2)
      N(M,1) = N(JJ,1) + LN(I1) + 1
      IGEN(KK,1)=0
      GO TO 6
C ================================================================
C     Vehicle exists in lane - Check if new vehicle from
C     file will fit
C ================================================================
    2 ITYPE = N(IY1,2)
      IDIST = N(IY1,1) - LN(ITYPE) - N(JJ,1)
C if the dist b/w generation point and rear of d/s vehicle is not
C large enough to accomodate req'd headway and veh. length then wait
      IF (IDIST.LE.(IGEN(KK,3)+LN(IGEN(KK,2)))) GO TO 45
C
C      enough room to place vehicle from file
```

```
C
      M = IGEN(KK,1)
      N(M,1) = N(IY1,1) - IGEN(KK,3) - LN(ITYPE)
      I1 = IGEN(KK,2)
      IGEN(KK,1) = 0
C
C     Update position arrays
C
    6 N(M,2) = I1
      SA(M) = LSPEED(IY,IL)*SMC*(1+ZB*Z(I1))
      N(M,3)=JJ
      N(M,8)=IY1
      N(IY1,3)=M
      N(JJ,8)=M
      N(M,6) = 0
      N(M,7) = 0
      N(M,5) = 0
      KLD(KK)=IS
      KTV(M)=IS
      N(M,4)=KK
      IF (IS.GE.IJ1) JGEN(1,KK)=JGEN(1,KK)+1
C       -keep separate record of trucks generated.
      IF ((IS.GE.IJ1).AND.(I1.GT.60)) JGEN(2,KK)=JGEN(2,KK)+1
C
C     Determine destination lane
C
      CALL RANDOM (IRNU)
      I1 = 0
      JZ=0
   10 I1=I1+1
      JZ=JZ+LS(KK,I1)
      IF (IRNU.GT.JZ) GO TO 10
C
      N(M,7)=I1
      IF (N(M,8).LE.MF) GO TO 7
      IF (SA(M).GT.SA(IY1)) SA(M) = SA(IY1)
C
C     if file is empty generate a new vehicle
C       remember that if restricted lane, no trucks can be generated
C
    7 IF (IGEN(KK,1).GT.0) GO TO 45
C
    1 M = MO + 1
      MO = M
      IF (MO.GT.2499) MO = MF+1
      IF ((N(MO,1).LE.N(1,1)).AND.(N(MO,1).GT.0)) WRITE
     # (*,100) MO,N(MO,1)
    4 RNU=RND()
      IRNU=IFIX((RNU*10000)+1)
      I1 = 0
      JZ = 0
    5 I1 = I1+1
      IF (I1.GT.100) GO TO 35
      JZ = JZ + NP(I1)
      IF (IRNU.GT.JZ) GO TO 5
      IF ((I1.GT.60).AND.(LRSTRCT.EQ.IY-2)) GO TO 4
      GO TO 41
   35 I1=I1-1
      IF (NP(I1).LE.0) GO TO 35
C
C     generate time headway-note distribution produced
C       is shifted negative exponential.  note that shift, C, is
C       required to reflect minimum acceptable gap size.
C       C varies with vehicle speeds.
C
C      - avg inter-arrival time tbar = 3600sec/h div vol(vph)
   41 TBAR = 3600.0/FLOAT(LM(IM,KK))
C       -determine shift based on speed of d/s vehicle.
   42 RNU=RND()
      IF (RNU.EQ.0.0) GO TO 42
      C=0.5+(0.55*FLOAT(LM(IM,KK))/1000)
      IF (C.LT.0.8) C=0.8
      T = C-(ALOG(RNU)*(TBAR-C))
C       -convert time headway into spatial separation
      IF (IY1.GT.MF) THEN
        H = SA(IY1)*T - FLOAT(LN(N(IY1,2)))
      ELSE
        H = 90.0*T
      ENDIF
      IF(H.LT.15.0) H = 15.0
      IGEN(KK,3) = IFIX(H)
      IGEN(KK,2) = I1
      IGEN(KK,1) = MO
C
C      -maybe another can be placed so check.
C
      GO TO 3
C
   45 LL(IY) = JJ
      LF(IY) = N(JJ,3)
   55 RETURN
C
  100 FORMAT (/,' VEHICLE NUMBER ',I4,' ALREADY EXISTS!:POSIT.',I6,/)
      END
C
C
      SUBROUTINE FIXEDOBJ(IY,JJ)
C
C     Fixed object procceser.
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
C
      K=N(JJ,2)
      IF (K.LE.21) GO TO 5
      IF (K.EQ.22) GO TO 10
      IF (K.LT.70) GO TO 5
      IF (K.EQ.90) GO TO 10
      IF (K.EQ.70) IL=IL+1
      IF (K.EQ.80) IK=IK+1
    5 LL(IY) = JJ
      LF(IY) = N(JJ,3)
      GO TO 15
   10 KK = N(JJ,4)
      CALL GENERATE (IY,JJ,KK)
   15 RETURN
      END
C
C
      SUBROUTINE RANDOM(IRNU)
C
      RNU = RND()
      IRNU = IFIX(RNU*100)
      IRNU = IRNU + 1
      RETURN
      END
C
C
      SUBROUTINE DESIRED(IY,JJ,KDER)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
C
      DESDIST = 1500
      KDER=0
      LT = LC(IK,IY)
      IF (LT.EQ.3) GO TO 45
C       check CURRENT physical section to see if desires lane change
      IF (N(JJ,7).LT.LJ(IK,IY)) KDER=1
      IF (N(JJ,7).GT.LK(IK,IY)) KDER=2
C       check if driver will look d/s beyond current section
      JIK = IK
   10 IF (KDER.GT.0) GO TO 30
      IF (JIK.EQ.1) GO TO 30
      IF ((LD(JIK)-N(JJ,1)).GE.DESDIST) GO TO 30
      JIK = JIK - 1
C       - if not a traffic lane then exit
      IF ((LJ(JIK,IY).EQ.99).OR. (LK(JIK,IY).EQ.99)) GO TO 30
      IF (N(JJ,7).LT.LJ(JIK,IY)) KDER=1
      IF (N(JJ,7).GT.LK(JIK,IY)) KDER=2
      GO TO 10
C       if due to lane type a change is not possible, don't try one
   30 IF ((KDER.EQ.1).AND.(LT.EQ.1)) KDER = 0
      IF ((KDER.EQ.2).AND.(LT.EQ.2)) KDER = 0
      IF (KDER.EQ.1) JCHANGE(6,1)=JCHANGE(6,1)+1
      IF (KDER.EQ.2) JCHANGE(7,1)=JCHANGE(7,1)+1
   45 RETURN
      END
C
```

```
      SUBROUTINE REQUIRED(IY,JJ,KDES,KO)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
C
      KO=0
      KZ = LC(IK,IY)
      KDES=0
C       move to left
      IF (N(JJ,7).LT.LJ(IK,IY)) KDES=1
C       move to right
      IF (N(JJ,7).GT.LK(IK,IY)) KDES=2
C       no move
      IF (KDES.EQ.0) GO TO 4
C       record manoeuvres
      IF (KDES.EQ.1) JCHANGE(4,1)=JCHANGE(4,1)+1
      IF (KDES.EQ.2) JCHANGE(5,1)=JCHANGE(5,1)+1
C       KO = posit of downstream border of phys sect.
      KO=LD(IK)
C       its possible that vehicle has missed its exit, if so, then
C       change destination to prevent vehicle from stopping at d/s
C       physical boundary.
C       if lane change to left is required but not in right or centre
C       lane, change dest to low mandatory.
    4 IF ((KDES.EQ.1).AND.((KZ.NE.0).AND.(KZ.NE.2)))
     #   N(JJ,7) = LJ(IK,IY)
C       if change to right required but not in left or centre lane,
C       change dest to mandatory high.
      IF ((KDES.EQ.2).AND.((KZ.NE.0).AND.(KZ.NE.1)))
     #   N(JJ,7) = LK(IK,IY)
      RETURN
      END
C
C
      SUBROUTINE PASSING (MX,IY,IR,IA)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
C
      IR=0
      IA=0
      KY=N(MX,2)
      KZ=LC(IK,IY)
      IF (KZ.EQ.3) GO TO 50
C       -if in right lane and lane to left is restricted and veh=truck
      IF ((KZ.EQ.2).AND.(KY.GT.60).AND.(LRSTRCT.EQ.(IY-3))) GO TO 50
      JDS=INT(LSPEED(IY,IL)*SMC*(1+ZB*Z(KY)))
      SX=SA(MX)
      M1=N(MX,8)
      IMD=N(MX,1)
C
      CALL ACCEL(MX,SX,IY,10,AC)
      AC1=AC
C
      CALL FOLLOW(M1,MX,0,0,KACC)
C
      IF (KACC.LT.0) GO TO 5
      IF ((KACC.LT.10).AND.(SX.LT.(JDS-10))) GO TO 5
C
    3 IF (KZ.EQ.2) GO TO 50
      IF (AC1.GE.0) GO TO 4
C
C     Yield if can't maintain speed
C
      JFN1=(-1)*AC1*(JDS-SX)*1.6
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(3,1)=JCHANGE(3,1)+1
      CALL RANDOM(IRNU)
      IF ((IRNU.GT.JFN1).OR.(IRNU.GT.80)) GO TO 12
      IA=2
      IR=3
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(3,2)=JCHANGE(3,2)+1
      GO TO 50
C
C     Consider vehicles which can maintain speed
C     but are very slow
C
    4 IX1=N(MX,1)+SA(MX)
      M2=N(MX,3)
      IF (M2.LE.MF) GO TO 12
      CALL FOLLOW(MX,M2,IX1,0,KACC)
      KACC1=KACC
      MR1=LL(IY+1)
      CALL FOLLOW(MR1,MX,0,0,KACC)
      IF ((KACC1.GE.0).OR.(KACC.LE.0)) GO TO 12
      CALL RANDOM(IRNU)
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(9,1)=JCHANGE(9,1)+1
      IF (IRNU.GT.5) GO TO 12
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(9,2)=JCHANGE(9,2)+1
      IR=6
      IA=2
      GO TO 50
C
C     determine if driver is frustrated enough to pass
C
    5 IF (AC1.LE.0) GO TO 3
      IF (M1.LE.MF) GO TO 12
      CALL RANDOM(IRNU)
      JFN2=(AC1*(JDS-SX)/10)
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(8,1)=JCHANGE(8,1)+1
      IF ((IRNU.GT.JFN2).OR.(IRNU.GT.40)) GO TO 50
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(8,2)=JCHANGE(8,2)+1
      CALL TIMEGAP(M1,MX,ISEC)
      ISEC1=ISEC
      IF (KZ.EQ.1) GO TO 6
      ML1=LL(IY-1)
      CALL TIMEGAP(ML1,MX,ISEC)
      ISECL=ISEC
      GO TO 7
    6 ISECL=0
    7 IF (KZ.EQ.2) GO TO 8
      MR1=LL(IY+1)
      CALL TIMEGAP(MR1,MX,ISEC)
      ISECR=ISEC
      GO TO 9
    8 ISECR=0
    9 ISECL=ISECL-ISEC1
      IF (ISECL.LT.0) ISECL=0
      ISECR=ISECR-ISEC1
      IF (ISECR.LT.0) ISECR=0
      IF ((ISECL.EQ.0).AND.(ISECR.EQ.0)) GO TO 50
      IA=1
      IF (ISECR.GT.(5*ISECL)) IA=2
      IF (IA.EQ.1) GO TO 11
C
C     determine if vehicle will pass on right
C
      CALL RANDOM(IRNU)
      JFN3=(ISECR-13)*0.73
      CALL FOLLOW(MR1,MX,0,0,KACC)
      IF ((IS.LT.IJ1).OR.(IMD.LT.KST(1)).AND.(IMD.LE.KST(2))) GO TO 10
      JCHANGE(2,1)=JCHANGE(2,1)+1
      JCHANGE(2,2)=JCHANGE(2,2)+1
      IR=2
   10 IF (KACC.LT.0) GO TO 12
      IF ((IRNU.LE.JFN3).AND.(IRNU.LE.40)) GO TO 50
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(2,2)=JCHANGE(2,2)-1
      GO TO 12
C
C     determine if vehicle will pass on left
C
   11 CALL RANDOM(IRNU)
      JFN4=(ISECL-13)*1.15
      CALL FOLLOW(ML1,MX,0,0,KACC)
      IF ((IS.LT.IJ1).OR.(IMD.LT.KST(1)).AND.(IMD.LE.KST(2))) GO TO 13
      JCHANGE(1,1)=JCHANGE(1,1)+1
      JCHANGE(1,2)=JCHANGE(1,2)+1
      IR=1
   13 IF (KACC.LT.0) GO TO 12
```

```
      IF ((IRNU.LE.JFN4).AND.(IRNU.LE.40)) GO TO 50
      IF ((IS.GE.IJ1).AND.(IMD.GE.KST(1)).AND.(IMD.LE.KST(2)))
     # JCHANGE(1,2)=JCHANGE(1,2)-1
   12 IA=0
      IR=0
   50 RETURN
      END
C
C
      SUBROUTINE TIMEGAP(IVEH1,IVEH2,ISEC)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
C
C        set up components of quatratic equation in order to solve
C        for time when both vehicles are at the same position.
C
      IF (IVEH1.LE.MF) GO TO 5

      JBA = (N(IVEH1,5) - N(IVEH2,5))/2
      JBB = INT(SA(IVEH1) - SA(IVEH2))
      JBC = N(IVEH1,1) - N(IVEH2,1)
C        calc the descriminant
      JBD = JBB*JBB - 4*JBA*JBC
C
      IF (JBD.LT.0) GO TO 5
      ISEC = (-JBB + SQRT(JBD))/2
      IF (ISEC.LT.0) GOTO 5
      GOTO 10
C
    5 ISEC = 500
   10 RETURN
      END
C
C
      SUBROUTINE FOLLOW (IVEH1,IVEH2,IX1,IX2,KACC)
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A6/ KA,KB,IN,LN(100),MD
C
C     IVEH1 is the downstream veh.
C     IVEH2 is the upstream veh.
C
      IF (IX1.EQ.0) IX1=N(IVEH1,1)
      IF (IX2.EQ.0) IX2=N(IVEH2,1)
      IF (IVEH1.GT.MF) GO TO 1
      KACC=0
      GO TO 3
    1 S1=SA(IVEH1)
      KYA=N(IVEH1,2)
      ILEN=LN(KYA)
    2 S2=SA(IVEH2)
      KY=N(IVEH2,2)
      KF=10*NF(KY)
      JCO=KF
      VD=S1-S2
      IF (VD.GT.10) JCO=0
      KACC=2*1000*(IX1-IX2-ILEN-10-(10*KI+KF)*S2
     #/100-JCO*(VD)**2/3000)/(KI*KI+2*KI*KI/10)
C
    3 RETURN
      END
C
C
C
C
C
C
C
C
C
      SUBROUTINE VEHICLES(IY,JJ)
C
C
C
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A11/ IGEN(20,3),LRSTRCT
C
C
      IR=0
      KO=0
      KY=N(JJ,2)
      MA = LL(IY)
      KZ = LC(IK,IY)
      MZ = N(JJ,6)
      IF (MZ.GT.0) GO TO 11
      IF (KZ.EQ.3) GO TO 11
      CALL REQUIRED(IY,JJ,KDS,KO)
      KOR=KO
      CALL DESIRED(IY,JJ,KDR)
      IF (KDS.NE.0) IR=5
      IF (KDS.EQ.0) GO TO 1
      IF (KDS.EQ.1) GO TO 5
      GO TO 4
C
C
C
       -if vehicle is truck ensure it doesn't desire to move
C        into a truck restricted lane.
C
C
```

```
C
    1 IF ((KDR.EQ.1).AND.(N(JJ,2).GT.60).AND.((IY-3).EQ.LRSTRCT))
     # KDR = 0
      IF ((KDR.EQ.2).AND.(N(JJ,2).GT.60).AND.((IY-1).EQ.LRSTRCT))
     # KDR = 0
      IF (KDR.NE.0) IR=4
      IF (KDR.EQ.1) GO TO 5
      IF (KDR.EQ.2) GO TO 4
C
      IF (N(JJ,5).GE.1) GO TO 11
      IF ((N(JJ,3).LE.MF).OR.(N(JJ,8).LE.MF)) GO TO 11
C
C       - if truck is in a restricted lane, desired to move to right.
C
      IF ((N(JJ,2).GT.60).AND.(LRSTRCT.EQ.IY)) GO TO 4
C
      CALL PASSING (JJ,IY,IR,IA)
      IF (IA.EQ.0) GO TO 11
      IF (IA.EQ.1) GO TO 5
C     ==== MOVE TO THE RIGHT =====
    4 IF (KZ.EQ.2) GO TO 11
      ID = IY+1
      CALL REQUIRED(ID,JJ,KDS,KO)
      IF (KDS.EQ.1) GO TO 11
      IF (IA.EQ.2) THEN
        CALL DESIRED(ID,JJ,KDR)
        IF (KDR.GT.0) GO TO 11
      ENDIF
      CALL CHECK(MA,JJ,IY,ID,KOR,IR,IH)
      IF (IH.EQ.1) GO TO 12
      GO TO 11
C     ==== MOVE TO THE LEFT ====
    5 IF (KZ.EQ.1) GO TO 11
      IF ((LRSTRCT.EQ.(IY-3)).AND.(KY.GT.60)) GO TO 11
      ID=IY-1
      CALL REQUIRED(ID,JJ,KDS,KO)
      IF (KDS.EQ.2) GO TO 11
      IF (IA.EQ.1) THEN
        CALL DESIRED(ID,JJ,KDR)
        IF (KDR.GT.0) GO TO 11
      ENDIF
      CALL CHECK(MA,JJ,IY,ID,KOR,IR,IH)
      IF (IH.EQ.1) GO TO 12
   11 CALL FMOVE(MA,JJ,IY)
   12 RETURN
      END
C
C
C
C
C
C
C
C
```

```
C
C

C
      BLOCK DATA
C
      COMMON /A1/ N(2500,8),SA(2500),LL(10),LF(10),IT,MF
      COMMON /A2/ IU,JF,JG,ITL,JM,KT,MI,MN
      COMMON /A3/ LA(2,20,8),LB(2,20,8),LX(10),KI,ML
      COMMON /A4/ LI(30,10),NF(100),NJ(100)
      COMMON /A5/ LM(30,10),NP1(100),LS(20,20),NP(100),MO
      COMMON /A6/ KA,KB,IN,LN(100),MD
      COMMON /A7/ IS,MG,MT,IP,IJ1,KST(2)
      COMMON /A8/ IK,IL,LC(30,10),NUMCARS
      COMMON /A9/ LD(30),LJ(30,10),LK(30,10)
      COMMON /A10/ TCH(100,3)
      COMMON /A11/ IGEN(20,3),LRSTRCT
      COMMON /A12/ JVOL(20,8),JSPEED(2,20,8),JSUM(3,20,8)
      COMMON /A13/ JTRUCKS(20,8,2),KSP
      COMMON /A14/ KLD(20)
      COMMON /A15/ IM,JPER(30),IMTIME(30),IMSIM(2),IMTOT
      COMMON /A16/ JCHANGE(9,3),JGEN(2,20)
      COMMON /A18/ MAC(7),MDC(7),LSPEED(10,20),SMC,ZB,Z(100)
      COMMON /A19/ KTT(6,20,20),KTV(2500)
      COMMON /A20/ NDIST(20,20)
      COMMON /A21/MAN(10,100,8),JTME(6,100),MTOT(6,100),IVTC(100),MAXC
      COMMON /A22/ NN1(2500)
C
C
C
C

      DATA LL/10*0/,LF/10*0/,LX/10*0/
      DATA NJ/100*40/
      DATA NF/100*0/,KLD/20*0/
      DATA MAC/48,48,48,44,35,26,17/
      DATA MDC/-72,-61,-53,-48,-48,-48,-48/
C
C
C
C
C        - note: SMC = speed mean constant i.e.
C                Speed limit * SMC = mean speed
C        - note: ZB  = normal variate coefficient used to
C                increase or decrease variance as mean changes.
C
C
C
C
C
      DATA SMC/1.1/,ZB/0.09/
      DATA LI/300*0/,LC/300*0/
      DATA NP/100*0/,LA/320*0/,LB/320*0/
      DATA LS/400*0/,LJ/300*0/,LK/300*0/,LD/30*0/
      DATA IGEN/60*0/,LN/100*0/,LRSTRCT/1*0/
      DATA JVOL/160*0/,JSPEED/320*0/,JSUM/480*0/
      DATA JTRUCKS/320*0/
      DATA JCHANGE/27*0/,JGEN/40*0/
      DATA KTT/2400*0/,KTV/2500*0/
      DATA NN1/2500*0/
      DATA MAN/8000*0/,JTME/600*0/,MTOT/600*0/,IVTC/100*0/,MAXC/1*0/
C
      END
```

Appendix C

User's manual

C.1 Hardware requirements

Hardware requirements for FREEVU are as follows:

- IBM PC compatible computer with a math co-processor (practical run times necessitate having an 80386 processor running at 20Mhz or more).
- VGA graphics card and colour monitor.
- a minimum of 640K of RAM.

FREEVU consists of 4 program files **all of which must reside on the same directory**.

`FREEVU.EXE` → Design shell
`SIMULATE.EXE` → Simulator
`EGAVGA.BGI` → Graphics driver
`LITT.CHR` → Character font

C.2 Tutorial

In this tutorial, an example freeway section will be examined, the data describing this section will be input, a simulation run, and the results analyzed.

The following typeface is used in this tutorial session to distinguish between text, user input, and FREEVU's prompts:

SMALL CAPS for menu option and program names.

`typewriter` for FREEVU prompts.

sans serif for user inputs.

The following terms are used throughout this tutorial:

section - the entire freeway portion being modelled.

segment - the specific homogeneous portion of the section as defined by the user.

upstream - in the direction against traffic flow.

downstream - in the direction with traffic flow.

location - distance in metres from beginning of section.

C.2.1 General data input

Data input is rather straight forward. For most required numerical input, a default value is given. If this value is acceptable, the user simply hits {`Return`}. If the value is not acceptable, a new value can be entered using the keyboard. As a value is entered, the digits will appear left justified in the input cell. The value can be edited using the {`Backspace`} key and the {←} key.

In the case of the Lane Type and Physical Feature input cells, a menu will appear when input to these cells is required. A selection from the menu can be made using the arrow keys and hitting {`Return`} or simply by entering the option key shown in red in front of the menu option. Hitting {`Escape`} at any time will return control to the menu.

Limitations

Due to computer hardware and software limitations, the restrictions presented in Table C.1 have been selected for FREEVU.

Table C.1: Restrictions applicable to FREEVU

Item	Maximum # Permitted
Section length	10 km
Traffic lanes	8
Entrances, including on ramps	20
Exits	20
Detector locations	20
Geometric segments	15
Speed limit zones	20
Vertical alignment segments	20
Different vehicle types	100
Vehicles on section at one time	2500

Freeway section

Assume the freeway section to be modelled has a plan and profile as depicted schematically in Figures C.1 and Figure C.2 respectively. Realize that the freeway section depicted is fictitious and the presence of the single on ramp merging on the left simply exists to demonstrate the versatility of FREEVU, and does not imply good design practice.

The user should sketch a plan and profile of the freeway section being simulated in the same format as depicted in Figures C.1 and C.2. This sketch need not be to scale or rigorously prepared, it need only reflect the geometry of the section being modelled. This will enable the user to more quickly input the necessary data into FREEVU and help prevent erroneous input.

FREEVU is invoked by going to the subdirectory containing the program and entering:

```
Freevu ↩
```

Section geometry input

From the main menu the user selects CREATE A NEW SECTION and from subsequent menus, INPUT NEW SECTION DATA and SECTION GEOMETRY.

At this point the user is prompted:

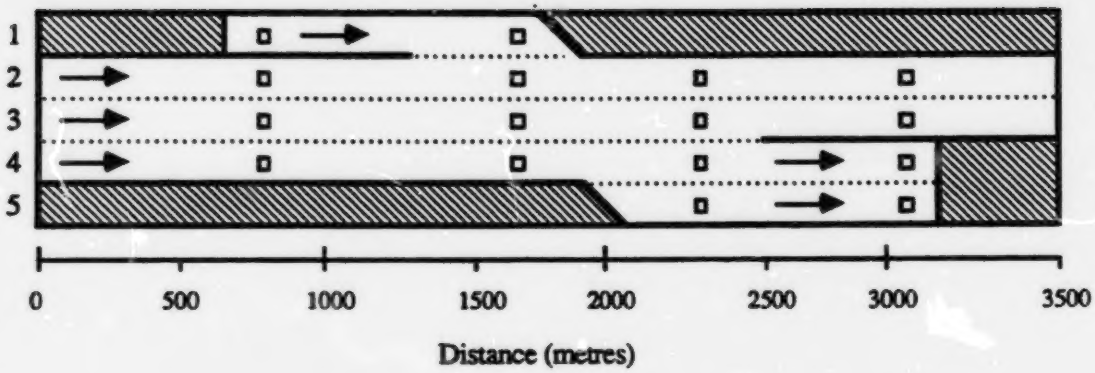

1
2
3
4
5
0
500
1000
1500
2000
2500
3000
3500
Distance (metres)

Figure C.1: Plan view of freeway section to be modelled

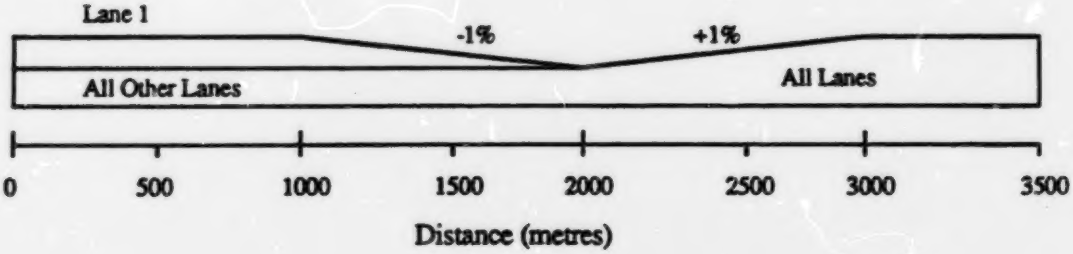

Lane 1
-1%
+1%
All Other Lanes
All Lanes
0
500
1000
1500
2000
2500
3000
3500
Distance (metres)

Figure C.2: Profile of freeway section to be modelled

```
Enter the total length of freeway section (metres):  3500
Enter the number of lanes at maximum width:  5
```

A new screen will appear presenting the user with an input form for specifying lane types and physical features in each lane. The user must begin by specifying the downstream boundary location of the first segment in lane 1. Consider the geometry of lane 1 only, as illustrated in Figure C.3.

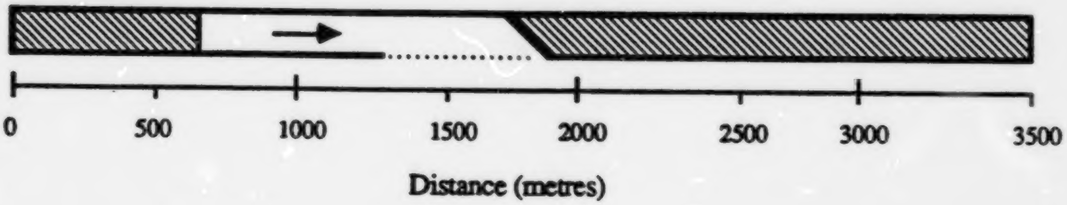


Figure C.3: Geometry of lane 1

It can be seen from Figure C.3 that lane 1 doesn't actually begin as a traffic lane until the on ramp start at 700 metres. After the on ramp start, the lane is a single lane until after the bull nose, at 1300 metres. The lane becomes a left lane at that point, as vehicles now have 500 metres in which to accelerate and merge to the right. At 1800 metres the acceleration lane ends in a lane drop, and the lane is no longer a traffic lane for the rest of the modelled freeway section.

From the previous paragraphs description of lane one's geometry, four homogeneous segments can be identified:

1. the segment prior to the on ramp start,
2. the segment from the on ramp start to the bull nose,
3. the acceleration lane, and
4. the absence of a traffic lane for the rest of the modelled segment.

These four segments can be input into FREEVU as illustrated in Figure C.4.

Similarly, data can be input for lanes 2, 3, 4 and 5. The correct user inputs for each lane are illustrated in Figure C.5.

Lane	Section	From (m)	To (m)	Physical Feature	Lane Type
1	1	0	700	System Start	None
	2	700	1300	On Ramp Start	Only
	3	1300	1800	Bull Nose	Left
	4	1800	3500	Lane Drop	None

Figure C.4: Geometry data input for lane 1

Detector information

All of the inputs defining the geometry of the freeway section are completed, however, the detectors must still be placed, and this is done by entering `ESCAPE` to return to the menu and then by selecting DETECTORS.

The user will be prompted:

```
Enter the total number of detector locations:  4
```

A new input form will appear and the user will be required to define the location of each of the detector positions (Figure C.6).

Vertical alignment

Since the freeway section profile includes grades other than zero, the profile must be defined. This is done by selecting VERTICAL GRADES from the menu. In defining the profile, homogeneous segments with respect to grade must be defined. Note that these segments are not related to those defined when describing the geometry of the freeway section. The data required to define the profile for the freeway section is presented in Figure C.7.

Posted speed limits

The on ramp in lane 1 has a posted speed limit of 60 km/h. Similarly, the two lane off ramp has a posted speed limit of 80 km/h beginning from the bull nose. The remainder of the freeway section has a posted speed limit of 100 km/h. In order

Lane	Section	From (m)	To (m)	Physical Feature	Lane Type
2	1	0	1300	System Start	Left
	2	1300	1800	Lane Type Change	Centre
	3	1800	3500	Lane Type Change	Left

Lane	Section	From (m)	To (m)	Physical Feature	Lane Type
3	1	0	2500	System Start	Centre
	2	2500	3500	Lane Type Change	Right

Lane	Section	From (m)	To (m)	Physical Feature	Lane Type
4	1	0	2000	System Start	Right
	2	2000	2500	Lane Type Change	Centre
	3	2500	3200	Bull Nose	Left
	4	3200	3500	Off Ramp End	None

Lane	Section	From (m)	To (m)	Physical Feature	Lane Type
5	1	0	2000	System Start	None
	2	2000	3200	Lane Add	Right
	3	3200	3500	Off Ramp End	None

Figure C.5: Geometry data input for lanes 2, 3, 4 and 5

Detector Location #	Location (metres)
1	800
2	1600
3	2250
4	3100

Figure C.6: Detector data input

		Percent Grades				
From	To (m)	Lane 1	2	3	4	5
0	1000	0	0	0	0	0
1000	2000	-1	0	0	0	0
2000	3000	1	1	1	1	1
3000	3500	0	0	0	0	0

Figure C.7: Vertical curvature data input

to specify these different speed limits, the user must select SPEED LIMITS from the menu.

The data input necessary for defining the speed limits is shown in Figure C.8.

This concludes the data input requirements for defining the freeway section. In order to save this section for subsequent simulation, the user must select EXIT TO PREVIOUS MENU and then select SAVE SECTION DATA ON DISK.

The user will be prompted for a file name. Any name of less than 9 letters is acceptable.

`Enter filename to save data to:` EXAMPLE

Having saved the data, the user can display the newly input section by returning to the main menu and selecting DISPLAY PREVIOUSLY DEFINED SECTION.

If the user is satisfied with the section displayed, the initiation of the simulation can proceed. If the user wishes to modify the section in some way, the option MODIFY EXISTING SECTION should be selected.

		Speed Limit (km/h)				
From	To (m)	Lane 1	2	3	4	5
0	700	100	100	100	100	100
700	1300	60	100	100	100	100
1300	2500	100	100	100	100	100
2500	3200	100	100	100	80	80
3200	3500	100	100	100	100	100

Figure C.8: Speed limit data input

C.2.2 Initialize and execute simulation

This menu option allows the user to define the necessary simulation control parameters and subsequently begin the simulation. Having selected this option, the next menu has five options;

1. Define Simulation Parameters
2. Alter Default OD Matrix
3. Save Parameters
4. Begin Simulation
5. Exit To Main Menu

If no parameters have been previously defined for the section which is to be simulated, then the first option is chosen. If parameters already exist on disk, then the simulation can be started immediately.

For the example being discussed, no parameters exist, therefore choose the option Define Simulation Parameters.

Define Simulation Parameters

Simulation parameters are those controls necessary to define the simulation characteristics, other than the geometry of the freeway section. The user is first prompted to enter the total simulation time desired in minutes. Having defined this total time, the user is prompted for the start and stop times during which animation data will be recorded. Also the user is prompted to define the portion of the freeway section over which lane change will be recorded for output files LNCHGS and MANOEUVR. The option to record animation data for only a portion of the simulation is implemented because the animation data requires a large amount of disk space. If a long simulation time is desired, then it is strongly recommended that only a portion, say 3-10 minutes of the simulation be recorded for animation purposes.

Having defined the total simulation time duration, it is necessary to define the desired volumes to be generated at the upstream boundary of each lane and the percent trucks in the traffic stream. Since it is often desirable to vary the volume over time in order to effectively simulate the growth and decline of traffic volumes, the total simulation time is divided into a number of time period. For each period, desired volumes are defined for each entrance lane.

It should be noted that the designated time periods need not be of uniform duration. The only restrictions are; each period must be some multiple of a whole minute; the minimum duration of any period is one minute; each period begins when the previous period ends; and the ending time of the last period can not exceed the total simulation time defined previously.

Also, measures of traffic performance are aggregated in such a way as to provide mean values for each time period defined here. Thus it may be useful to have time periods of uniform duration to facilitate the analysis of results. More details on available output and the format of this output is given in Sections C.2.2 and C.3.

When the option DEFINE SIMULATION PARAMETERS has been chosen, the user will be prompted:

```
Total simulation time (minutes):  15
Time at which ''Movie'' data will START being recorded:  5
Time at which ''Movie'' data will STOP being recorded:  10
Upstream end of section in which manoeuvres recorded (m):  0
Downstream end of section in which manoeuvres recorded (m):  3500
Is passing lane restricted to truck traffic (Y/N): N
```

Having responded to each of the prompts a new screen will appear by which the user is prompted to specify the desired volumes for each entrance lane.

```
Total Simulation Time = 15 minutes
Time Period:  1 Start Time = 0 (min) Stop Time = 5 (min)
Percent Trucks in the Traffic Stream:  10
Define Desired Volume for each Entry Point:
Entrance       Desired Volumes
   1             600
   2           1000
   3           1000
   4           1000
```

The input specifies for the first 5 minutes of the simulation, 1000 vphpl for each through lane and 600 vphpl for the on ramp. For the next 10 minutes it is desired to increase the through lane volumes to 1600 vphpl and keep the on ramp volume constant at 600 vphpl. The necessary input for the second time period is:

```
Total Simulation Time = 15 minutes
Time Period:  2 Start Time = 5 (min) Stop Time = 15 (min)
Percent Trucks in the Traffic Stream:  10
Define Desired Volume for each Entry Point:
Entrance      Desired Volumes
   1           600
   2           1600
   3           1600
   4           1600
```

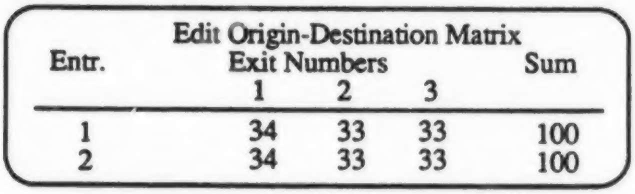
This illustrates all the input required. The origin-destination matrix can be altered if desired, but for this example application the default matrix will be accepted. The next section describes how the OD matrix can be altered if desired.

Alter Default OD Matrix

The origin-destination matrix is a matrix of probabilities used to assign destinations to each generated vehicle. Each exit point, whether it be the end of an off ramp or a through lane at the downstream end of the section, corresponds to a unique destination number.

When the user defines the geometry of the freeway section and defines traffic characteristics, no information regarding the proportion of traffic exiting at each exit point is required. During the translation of the user input data to the format required by the simulator, an origin-destination matrix is automatically produced based on the assumption that off ramps will accommodate 50% as much traffic as a through lane will. Thus the volume produced by each entrance lane is split according to the number of exit lanes and the number of off ramps.

If the user wishes to view or alter this default OD matrix, then this menu option should be selected. Upon selection, a screen as illustrated in Figure C.9 will appear presenting the current default OD matrix. Alterations can be made by the user



Edit Origin-Destination Matrix

Entr.	Exit Numbers 1	 2	 3	Sum
1	34	33	33	100
2	34	33	33	100

Figure C.9: Origin-Destination matrix alteration screen

remembering that the full 100% of traffic entering at each entrance lane must be distributed.

If the OD matrix is altered, and the section data is subsequently modified, the OD matrix reverts back to its default state.

Entrance and exit numbers correspond to those indicated on the plan view when the section is displayed. If it is physically impossible for traffic entering at some entrance point to leave the section at some exit, the OD entry will be 0 and can not be changed by the user.

It should be noted that the actual proportion of vehicles exiting at any one exit lane *may* not correspond to the input OD matrix.This is because there is a distinction between destination and exit lane. An exit lane is simply the lane in which a vehicle happens to be when passing the artificial boundary of the simulation, after which the vehicle is no longer considered in the simulation. A destination on the other hand, is not a lane, but the ultimate geographical location that the driver wishes to gain. This distinction is important because the OD matrix controls the destinations not the exit lane of the vehicles.

Consider the fictitious freeway section depicted in Figure C.10. If a vehicle wishes to ultimately make an exit at junction #2 then it can cross the artificial boundary of the simulation in any of the three through lanes that exist at that point, regardless of the specific exit number assigned to it. However, if the vehicle is to exit the freeway at junction #1, then it must be in lane 4 when it crosses the artificial boundary delineating the end of the simulation.

Thus when adjacent exit lanes exist such that the same destination can be gained by either lane, then it is assumed the driver doesn't care which of these adjacent lanes he/she exits the simulated section on. In reality, artificial boundaries do not exist across lanes, so drivers determine their lane from interactions with other traffic and their own characteristics. As such, the OD matrix only controls the *destinations* of traffic, not simply the lane by which the traffic exits the simulated section of freeway.

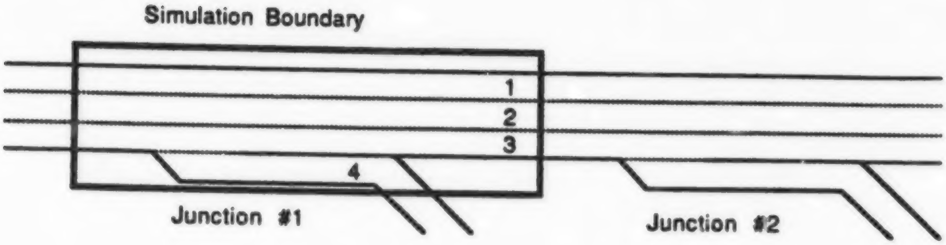


Figure C.10: Interpretation of origin-destination matrix

Save Parameters

Before a simulation can be started, all data must exist on disk. Thus in order to use the parameters defined, they must be saved. It is recommended that the parameter file be saved with the same name as the geometry file in order to make it easy to know which files belong together.

Begin Simulation

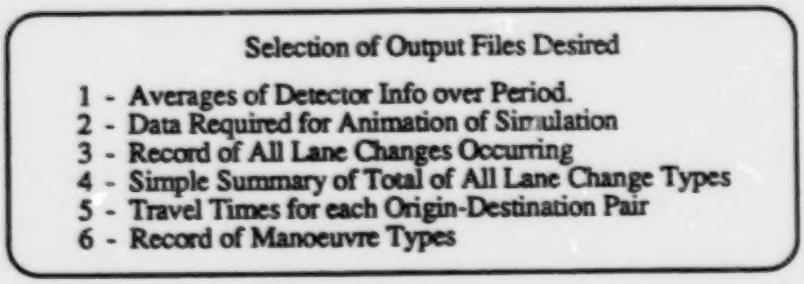
To proceed, the user selects an existing file from disk describing the geometry of a freeway section (a listing of all geometry data files on the selected directory will appear) and a file containing appropriate simulation control parameters. Note that the parameters must have been defined for the geometry file chosen. If the files are not compatible, an error message will be displayed and the user will be requested to select another parameter file.

Also note, that the vehicle data file, DATA.VEH, must also reside on the same directory as the geometry file and parameter file. If the user wishes to alter the driver sensitivity parameter, k, the appropriate value for each vehicle type in DATA.VEH must be changed.

Having selected the files, the user can select the output files desired for the simulation run. Six options which the user can choose from are presented on the screen as illustrated in Figure C.11.

For this example, all of the output files are selected except for the full lane change file (option 3), and then the letter B is entered to begin the simulation.

After the simulation is completed, the user can return to the main menu and view the animation by selecting EXAMINE EXISTING SIMULATION RESULTS and indicating the file to be viewed.



Selection of Output Files Desired

1 - Averages of Detector Info over Period.
2 - Data Required for Animation of Simulation
3 - Record of All Lane Changes Occurring
4 - Simple Summary of Total of All Lane Change Types
5 - Travel Times for each Origin-Destination Pair
6 - Record of Manoeuvre Types

Figure C.11: Available output options

A hard copy of the output files can be obtained by returning to DOS and typing:

```
Print AVERAGES LNCHGS MANOEUVR TIME
```

C.3 Output files

As previously described, there are four different output files available in hardcopy form from `FREEVU`. An example of each output file is presented here for the freeway section presented in Section C.2.

Output file `AVERAGES` (Figure C.12) is likely the most useful of the output files as it records the average volume, speed and density for each detector location on the section. As well, the total number of trucks and vehicles passing each detector station is provided. The actual produced volumes along with the user defined desired volumes are presented in the file header. A record for each detector is provided for each time period specified by the user.

Output file `MANOEUVR` (Figure C.13) contains the average time spent by each vehicle class, in making manoeuvres. Only those manoeuvres made during the specified time period and in the portion of the freeway section specified are considered. There may be a maximum of six vehicle classes (currently there are four — see Appendix A) and there are seven manoeuvre types (Table C.2).

Similar to the file `MANOEUVR` is the output file `LNCHGS` (Figure C.14). This file contains a summary record of all the lane changes made during the time period and which occurred within the user specified section. This file lists essentially the same manoeuvre types as noted in Table C.2 but distinguishes between mandatory and desired lane changes to the left and right.

```
==================================================================
        AVERAGE VOLUME, SPEED AND DENSITY VALUES
==================================================================
    ENTR # 1  SPEC. VOL  =   600      GENERATED VOLUME =  648 (vph)
    ENTR # 2  SPEC. VOL  =  1000      GENERATED VOLUME = 1320 (vph)
    ENTR # 3  SPEC. VOL  =  1000      GENERATED VOLUME = 1164 (vph)
    ENTR # 4  SPEC. VOL  =  1000      GENERATED VOLUME = 1176 (vph)
------------------------------------------------------------------
    SPECIFIED % TRUCKS =    10%                ACTUAL  =  7.0%
    MONITORED SIMULATION TIME   =     5 (MIN): SESSION =   1
------------------------------------------------------------------
        LANE #1 CORRESPONDS TO THE MEDIAN (PASSING) LANE:

              DETECTOR # 1

        LANE NUMBER             1    2    3    4    5
        VOLUME    (vph)          0 1476 1488  864  576 4404
        PERCENT IN LANE          0   33   33   19   13
        SPEED     (km/h)         0   80   79   78   87
        DENSITY   (v/km)         0   18   18   11    6
        # OF TRUCKS              0   10   13    7    4
        # OF VEHICLES            0  123  124   72   48
                                   .
                                   .
                                   .
==================================================================
```

Figure C.12: Portion of example output file **AVERAGES**

Table C.2: Manoeuvre types recorded

Number	Manoeuvre Description
1	Pass on the left to increase speed
2	Pass on the right to increase speed
3	Yield to the right because vehicle can not maintain current speed
4	Desired lane change
5	Mandatory lane change
6	Yield to the right because vehicle is blocking a faster vehicle behind it
7	Vehicle is decelerating at a rate which is greater than normal deceleration

```
===================================================================
    ENTR # 1  SPEC. VOL   =   600      GENERATED VOLUME =  648 (vph)
    ENTR # 2  SPEC. VOL   =  1000      GENERATED VOLUME = 1320 (vph)
    ENTR # 3  SPEC. VOL   =  1000      GENERATED VOLUME = 1164 (vph)
    ENTR # 4  SPEC. VOL   =  1000      GENERATED VOLUME = 1176 (vph)
    SPECIFIED % TRUCKS =    10%                ACTUAL  =  7.0%
===================================================================
    VEH CLASS     1     2     3     4     5     6     7
-------------------------------------------------------------------
         1       95    93     0   170    53    26   427
         2        0     0     0     1     0     0    10
         3        1     2     3    14     8     2    20
         4        0     0     0     0     0     0     0
===================================================================
                                  .
                                  .
                                  .
===================================================================
```

Figure C.13: Portion of example output file `MANOEUVR`

The output file `TIME` (Figure C.15) contains a record of the average travel time observed for cars and trucks, for each origin-destination pair. The standard deviation and actual number of observation for each OD pair is also provided.

C.4 Dealing with problems

Despite the user-friendliness of FREEVU problems can still occur. Most difficulties will simply result in an error message being produced and the user having to take some appropriate action, however, occasionally it is possible to cause the program to terminate execution. These fatal errors usually result from the user attempting to define an inappropriate freeway section.

Most errors will occur when the user attempts to define the freeway section geometry. If the user attempts to input an ineligible value, the input is not accepted and the user is notified. However, if the input is valid as it is but is not compatible with the other data entered, then an error may not be identified until the user attempts to save the data. At this time the data is checked for compatibility and completeness. Eleven errors are check for at this time. These are listed and described in Table C.3.

It is not possible to save the input data until all identified errors have been corrected. If an error occurs, the user must go back to the appropriate menu and input

```
=====================================================================
    ENTR # 1  SPEC. VOL  =   600      GENERATED VOLUME =  648 (vph)
    ENTR # 2  SPEC. VOL  =  1000      GENERATED VOLUME = 1320 (vph)
    ENTR # 3  SPEC. VOL  =  1000      GENERATED VOLUME = 1164 (vph)
    ENTR # 4  SPEC. VOL  =  1000      GENERATED VOLUME = 1176 (vph)
---------------------------------------------------------------------
    SPECIFIED % TRUCKS =    10%                ACTUAL  =  7.0%
    MONITORED SIMULATION TIME   =     5 (MIN): SESSION =   1
---------------------------------------------------------------------
    PASS ON LEFT                                              96
    PASS ON RIGHT                                             96
    MAX ACCEL <0-> YIELD                                       3
    SLOW W/ CAR BEHND-YLD                                     28
    MANDATORY LEFT                                             5
    MANDATORY RIGHT                                           56
    DESIRED LEFT                                              54
    DESIRED RIGHT                                            131
---------------------------------------------------------------------
    TOTAL TO LEFT                                            155
    TOTAL TO RIGHT                                           314
    TOTAL LANE CHANGES                                       469
=====================================================================
                                  .
                                  .
                                  .
=====================================================================
```

Figure C.14: Portion of example output file LNCHGS

```
==============================================================
         AVERAGE TOTAL TRAVEL TIMES (seconds)
--------------------------------------------------------------
CARS   ENTRANCE          EXIT LOCATION #
                      1        2        3        4
            1       144      149      130      119
            2       161      162      134      136
            3       152      151      129      126
            4       144      148      121      132
TRUCKS ENTRANCE          EXIT LOCATION #
                      1        2        3        4
            1       167      158      169      127
            2       176      182      155      141
            3         0      164      145      134
            4         0      157        0        0
==============================================================
         STANDARD DEVIATION OF TRAVEL TIMES
--------------------------------------------------------------
CARS   ENTRANCE          EXIT LOCATION #
                      1        2        3        4
            1        22       15       15       12
            2        18       15       11       15
            3        15       13       12        5
            4        14       10       10       12
TRUCKS ENTRANCE          EXIT LOCATION #
                      1        2        3        4
            1        23        0       14        0
            2        19       19       28       29
            3         0       17       11        0
            4         0        2        0        0
==============================================================
         TOTAL NUMBER OF OBSERVATIONS
--------------------------------------------------------------
CARS   ENTRANCE          EXIT LOCATION #
                      1        2        3        4
            1        14        6       14        5
            2        33       28       17       14
            3        34       35       15       10
            4        35       33       16       16
TRUCKS ENTRANCE          EXIT LOCATION #
                      1        2        3        4
            1         3        1        2        1
            2         7        2        2        2
            3         0        8        3        1
            4         0        2        0        0
==============================================================
```

Figure C.15: Portion of example output file TIME

Table C.3: Possible errors when saving data

Error	Description
1	Two or more detectors have the same location
2	At least one detector location = 0
3	At least one detector location is greater than length of section
4	Profile has not been specified for entire section
5	Lane type data not specified for all lanes
6	Physical features not specified for all lanes
7	At least one lane has no sections defined
8	All lanes have not been defined up to section length
9	Adjacent lane types are not all compatible
10	Speed limits have not been specified for entire section
11	No through lane exists. There must be at least 1

or modify the relevant data.

Error messages can also appear when retrieving or selecting files. Here it is important to observe the directory path being used for the search. If the path is not correct simply alter it until the desired directory is found.